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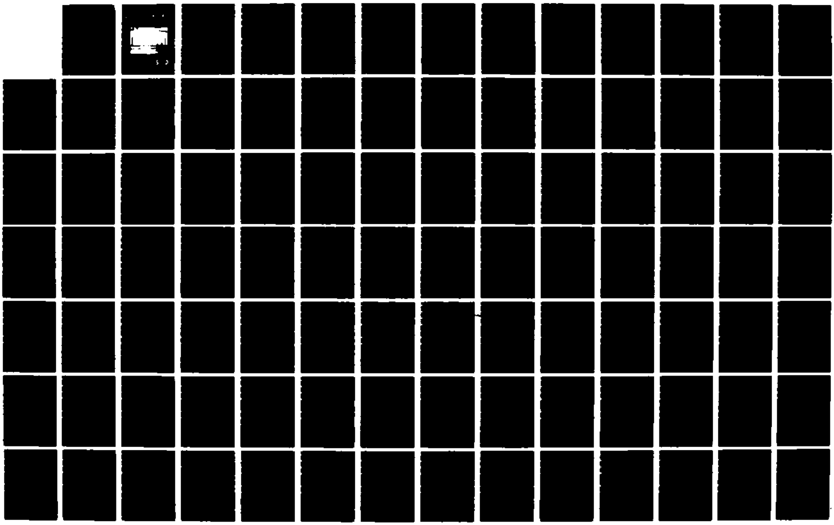

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East and the Air Force Office of Scientific Research with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work considered to be of special interest.

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CONTENTS

Cover: *Dosojin* are a type of deity and originally were guardians of roads and village boundaries and served the function of "obstructing" or "keeping out" evil spirits. Children are now considered special favorites of this deity. This photograph, contributed by Erin Moore, was taken at a roadside near the small coastal town of Hayama, Japan.

GROWTH OF SINGLE DOMAIN GaAs ON TWO-INCH Si SUBSTRATES

In an effort to integrate GaAs and Si devices, Oki Electric Industry Company, Ltd., has been growing GaAs on Si substrates by MOCVD and MBE. In the recent fourth progress meeting of Future Electron Devices, 3-4 July, they announced the successful growth of single domain GaAs on Si (100) substrates by MOCVD. Subsequently, they also reported the growth of single domain GaAs films with a good surface morphology on an entire area of two-inch Si (100) substrates by MBE.

The successful growth was attributed to initial thermal cleaning of Si substrates in the MBE system and subsequent low temperature growth of thin GaAs buffer layers. Si substrates covered with thin amorphous oxides remaining after removal of oxide layers by HF is thermally cleaned at 850°C. Then, about 100 Å GaAs buffer layers were grown at low temperatures (< 400°C). Final GaAs layers of 1.5 μm thickness grown on the buffer layer at 600°C exhibited single domain with a good surface morphology.

Yoon Soo Park
ONRFE/AFOSRFE

SYNCHROTRON FOR ULSIs

Nippon Telegraph and Telephone Corporation (NTT), in partnership with Hitachi, Ltd., and Toshiba Corporation is developing a 5-meter-diameter synchrotron to produce soft x-rays for x-ray lithography applications. The synchrotron facility will be located at NTT's new Atsugi Electrical Communications Laboratory and is expected to be completed by March 1988 at a cost of ¥20 billion ($80 million).

The synchrotron is intended for use in submicron lithography needed for production of ultra large-scale integrated (ULSI) circuits chips such as 64 megabit RAMs. NTT has been conducting an experiment to produce a submicron line width (0.1-0.2 microns) using a 10-meter-diameter synchrotron at the National Laboratory for High Energy Physics in Tsukuba. Sources say that NTT will soon launch a plan to make submicron chips including a 64 Mb RAM. Several Japanese chip makers--Toshiba and Hitachi--are testing IM chips and are ready to deliver samples early this fall.

Yoon Soo Park
ONRFE/AFOSRFE

PLANAR-DOPED QUANTUM WELL (PD-QW) HETEROSTRUCTURE

Workers at Fujitsu Laboratories, Ltd., at Atsugi have reported a new, novel heterostrufcture for the 2DEG system called "Planar-Doped Quantum Well (PD-QW) Heterostructure." In the PD-QW heterostructure, a Si-Planar doped (Si-Pd) AlAs-GaAs-AlAs quantum well structure is serving as a 2DEG supplying layer.

The structure grown by MBE consists of an 0.5 μm undoped GaAs layer, an undoped AlAs(15Å)-GaAs(20Å)-AlAs(15Å) space layer, a 20 Å Si-PD GaAs QW layer, an undoped AlAs (15Å)-GaAs (20Å) - AlAs (15Å) layer, and contact layers of 400 Å Si-doped $Al_{0.2}$ $Ga_{0.8}$ As and 200 Å GaAs. The Si-PD layer was formed on the middle Ga plane of the 20 Å GaAs quantum well layer to a sheet doping concentration of $0.6\text{-}4 \times 10^{12}$ cm^{-2} by impinging

only Si and As fluxes on a growth-interrupted surface of a GaAs epitaxial layer. In this structure, high-mobility 2DEG is formed at the undoped GaAs (0.5 μm)-AlAs (15 Å) heterojunction interface.

The structure exhibited a 2DEG mobility of 8.7×10^4 $cm^2/V.s$, a sheet concentration of 1.0×10^{12} cm^{-2}, a sheet resistivity of the 2DEG layer of 70 Ω/□ at 77 K. They claim that the sheet resistivity of 70 Ω/□ is the lowest observed so far in selectively doped heterostructure. The structure also showed a little persistent photoconductivity at low temperatures.

Because of the low sheet resistivity of the 2DEG layer and the short distance between the high mobility 2DEG layer and the Schottky contact, they speculate the (if the PD-QW heterostructure is applied to HEMTs) improvements in high-speed performance of HEMTs will result.

Yoon Soo Park
ONRFE/AFOSRFE

HIGH G_m -AlInAs/GaInAs HETEROSTRUCTURES

NEC workers have fabricated 1 μm-gate, 2DEGFETs with transconductances of 440 mS/mm at room temperature and 700 mS/mm at 77K using n-AlInAs/GaInAs heterostructures grown by MBE. The 2DEG mobilities of 12,000 $cm^2/V.s$ and 56,000 $cm^2/V.s$ are observed at room temperature and at 77 K, respectively. Planar 2DEGFETs are fabricated with Al gates and Ni/Au-Ge are employed as ohmic contacts. By inserting a thin surface undoped AlInAs layer, gate leakage current was minimized. Observed transconductances are the highest values reported for the 2DEGFETs.

Yoon Soo Park
ONRFE/AFOSRFE

LOW NOISE AMPLIFIER USING HEMT

A low noise amplifier incorporating HEMTs for use in satellite communication ground stations has been developed by Fujitsu Laboratories, Ltd., for the Ministry of Posts and Telecommunications. The amplifier is being tested in the experimental program of satellite communications in the frequency range of 20-30 GHz. The HEMT is cooled to -50°C by the Peltier effect. In the frequency range of 17.7 to 19.5 GHz, the amplifier exhibited a gain of 38 dB with a noise figure of 1.71 dB. This is the first utilization of an HEMT amplifier in a satellite communication systems.

Yoon Soo Park
ONRFE/AFOSRFE

COMPLEMENTARY GaAs SISFET: GaAs CMOS

At the 12th International Symposium on GaAs and Related Compounds held recently in Karuizawa, 23-26 September 1985, both workers of the Electrotechnical Laboratory and the NTT Atsugi Electrical Communication Laboratory announced the first demonstration of a new complementary GaAs SISFET structure employing AlGaAs heterostructure SISFETs. Both n- and p-channel SISFETs are integrated on a single GaAs substrate by MBE to form a complementary GaAs SISFET. In these structures, the high mobility character of both

two-dimensional electron and hole gases induced at the same AlGaAs/GaAs interfaces have been utilized to achieve very high speed and low-power consumption.

Different approaches are taken by the two laboratories to construct complementary SISFET structures. However, they both employ selective ion implantation, lamp annealing, and self-alignment technology. Achievements are significant in that they have demonstrated for the first time the feasibility of fabricating a GaAs CMOS version of a polysilicon gate MOSFET.

ETL STRUCTURE

The complementary GaAs SISFET structure fabricated by ETL consists of a n-channel having an n^+-GaAs/undoped AlGaAs/undoped GaAs structure and a p-channel having a p^+-GaAs/undoped AlGaAs/undoped GaAs structure. Serving as gate materials are n^+-GaAs in the n-channel SISFET and p^+ GaAs in the p-channel SISFET. An undoped GaAlAs layer inserted between the gate layer and an undoped GaAs channel layer forms an insulating layer in the SIS configuration. Following the growth of the p^+-GaAs layer on the substrate, the n^+-layer was grown on the substrate by the selective regrowth technique which involves the deposition of the WN layer and selective etching of p^+ and WN layers. Self-aligned source and drain regions in both the n-and p-channels were implanted with Si and Mg, respectively and lamp annealed.

The SISFET operates as a normally off-type FET with the threshold voltage of V_{th}=+0.025 V and the transconductance of 160 mS/mm at 77 K for the n-channel SISFET, and V_{th}=+0.05 V and the transconductance of 28 mS/mm at 77 K for the p-channel SISFET. The dependence of the current of the complementary SISFET as a function of the input gate voltage for different supply voltages clearly displayed complementary circuit characteristics.

It was observed that as the input voltage was increased, the current increases show a maximum value and then decreases.

NTT STRUCTURES

Instead of using n^+-and p^+-GaAs as gate materials, the complementary SISFET structure of NTT employs n^+-Ge as gate materials. The circuit is fabricated on an n^+-Ge/undoped GaAs (5 nm)/undoped $Al_{0.8}Ga_{0.2}$ As (30 nm)/undoped AaAs (300 nm) heterostructure. Except for the regions of n-channel FETs, an n^+-Ge layer is removed. WSi_x is deposited and the mesa is formed. Then, the gate patterns of WSi_x/n^+-Ge for the n-channel FET and WSi_x for the p-channel FET are delineated. Self-aligned source and drain regions are formed by Si and Be implantations for the n-channel FET and the p-channel/FET respectively.

The n-channel SISFET operated at a threshold voltage of 0.1 V with a transconductance of 160 mS/mm at room temperature, while the p-channel operated at a threshold voltage of -0.55 V with a transconductance of 30 mS/mm.

Using the complementary circuit, they fabricated a two-stage inverter with good transfer characteristics which showed a high voltage level of 1 V and a low voltage level of 0.02 V for a 1 V supply voltage at 83 K. They also fabricated a 15-stage ring oscillator with a minimum delay time of 125 ps at 300 K and 100 ps at 83 K for a 2.9 V supply voltage.

Unlike HEMTs, since the complementary SISFETs employ undoped AlGaAs, no

impurities diffuse into the heterointerface. Therefore, high electron and mobilities at the heterointerface can be retained even after annealing. The results reported by both ETL and NTT researchers demonstrate the potential of a new GaAs complementary circuit technology for high speed and low standby power LSI applications.

Yoon Soo Park
George B. Wright
ONRFE/AFOSRFE

LATE DEVELOPMENTS IN HEMT TECHNOLOGY AT FUJITSU LABORATORIES, LTD.

Yoon Soo Park

INTRODUCTION

Research and development activities of Fujitsu, Ltd., one of the world's leading manufacturers of computers, telecommunications equipment and systems, semiconductor devices and electronic components are being conducted at Atsugi and Kawasaki, two research centers of Fujitsu Laboratories, Ltd. The Atsugi Laboratory was newly established in June of 1983 in the city of Atsugi, Kanagawa prefecture, in order to lay the foundation for basic technologies of future information processing and communication systems. At Atsugi, all microelectronics, electronic devices, materials and components research and development activities of Fujitsu Laboratories are focused and consolidated. Activities in the development of information processing and telecommunications equipment and systems are being emphasized at the Kawasaki center.

The recently established Atsugi Laboratory was built at the cost of 10 billion yen ($40 million) and it has a total building area of 24,520 m², one-fifth of which is designated as clean room areas. It currently employs 450 research staff members, of which 10% are engaged in basic studies, 24% in semiconductors, 12% in components, and 10% in materials. Of a total of 970 staff members of Fujitsu Laboratories comprising the Kawasaki and Atsugi centers, 11% hold doctorate degrees, 36% master's degrees, and 11%, bachelor's degrees.

Fujitsu's accomplishments in key technology areas are impressive and they have achieved many "firsts" in many areas of discrete devices, large-scale ICs, and computers. For example, in 1978 they were the first company to market the 64 Kbit MOSDRAM. In 1980, they fabricated the first high electron mobility transistor (HEMT) using an AlGaAs-GaAs heterojunction system. Fujitsu's supercomputer VP-200, called the world's fastest supercomputer, capable of up to 500 Mflops, was made available to the public in 1982.

Besides internally funded projects, Fujitsu is actively engaged in the Ministry of International Trade and Industry (MITI)-sponsored large-scale national projects; for example, the supercomputer project, the optoelectronic project, and the future electron device project. Research and development of HEMT LSIs is being carried out under the High Speed Computer System for Scientific and Technological Uses Program (the supercomputer project) and superlattice devices work under the future electron devices portion of the Research and Development Project of the Basic Technology for Future Industries program.

In this report, some research activities and late developments in the areas of materials and processing technologies related to HEMT LSI technology presented to the author during his visits to the Atsugi Laboratory will be summarized. Reference materials on organization and scope of the Fujitsu Laboratories, Ltd., are listed in Appendix I.

At the Atsugi Laboratory, extensive research activities are being carried out in the following electronic device areas:

- HEMTs,
- GaAs ICs,

- silicon LSIs,
- Josephson junctions,
- optoelectronic devices,
- OEICs
- infrared devices,
- amorphous silicon devices,
- fine pattern technology,
- semiconductor materials growth,
- process technology,
- optical circuit components.

RESEARCH ACTIVITIES AND LATE DEVELOPMENTS

- HEMT LSI Technology

Since the first HEMT devices were demonstrated by Fujitsu in 1980, HEMT technology has become an active research and development target of many laboratories throughout the world as a leading technology of new generation switching devices. Fujitsu, like many other leading laboratories of the world, has been dedicating its resources to the perfection of the technology for applications to ultrahigh speed next generation computers. Recent achievements in HEMT LSI technology clearly demonstrates its leading role in the development and application of HEMT technology.

As a member of the Association for the Development of High Speed Scientific Computers which includes five other companies--Hitachi, NEC, Toshiba, Mitsubishi Electric, and Oki, Fujitsu's efforts in HEMT technology is strongly backed by MITI through the supercomputer project. The well-publicized MITI supercomputer calls for the development of a computer capable of performing at a speed of 10 GFlops (10 giga floating point operations per second) for applications in atmospheric sciences, aerodynamics, and nuclear energy research where large-scale numerical computations are required. The project began in 1981 and is to be completed in 1989 with a total nine-year budget of 23 billion yen ($92 million). The project involves, in addition to the research and development of parallel architecture and software, the research and development of new types of high speed, high integration logic and memory devices. The new devices specifically calls for investigations of a variety of possible alternatives to silicon devices such as Josephson junctions, HEMT and GaAs devices which are to be incorporated into the future supercomputers.

Targets of logic and memory devices envisioned in the project are:

- Logic Devices

  with a delay time of <10 ps/gate (JJ, HEMT),
  or <30 ps/gate (GaAs),
  with an integration level of >3000 gates/chip.

- Memory Devices

  with an access time of <10 ns,
  with an integration level of >10 Kb/chip.

With these specific goals, the Atsugi Laboratory is pursuing the exploration and perfection of materials, processing, and fabrication of HEMT LSI technology.

Achievements in the development of HEMT device technology are:

- Attainment of the highest 2DEG mobility of $\sim 2 \times 10^6 cm^2/V.s$ at 5 K in the selectively doped GaAs/N-AlGaAs heterostructures grown by MBE,

- demonstration of a 1.7 μm gate length, 27-stage HEMT ring oscillator with 17.1 ps switching delay and 1 mW power dissipation per gate at 77 K,

- fabrication of a low noise, microwave HEMT with a noise figure of 0.35 dB and an associated gain of 12 dB at 12 GHz and 100 K,

- application of the HEMT in a 20 GHz, four-stage, microwave amplifier with noise of 3.9 dB and 30 dB gain at room temperature,

- operation of a HEMT frequency divider with master-slave flip-flop divide-by-two circuits at 8.9 GHz at 77 K and 5.5 GHz at room temperature,

- fabrication of a HEMT 1 Kb SRAM with an access time of 0.87 ns with a power dissipation of 360 mW at 77 K and a HEMT 4 Kb SRAM with an access time of 2.0 ns with a power dissipation of 1.6 W at 77 K.

- Materials Growth

Since the first demonstration of the HEMT in 1980, workers at Fujitsu have continued to improve the material quality and electron mobility of quasi two-dimensional electron gas (2DEG) in selectively doped GaAs/N-AlGaAs heterostructures. At Fujitsu, the molecular beam epitaxy technique is extensively employed for heterostructure growth, though there are some efforts to grow the structure by MOCVD. Besides the Varian Gen II MBE machine, there are several MBE machines in the laboratory. Other than the HEMT structure, superlattices and quantum well optical devices are also being fabricated in these MBE systems.

The latest measured mobility values reported by the Fujitsu workers are 195,000 $cm^2/V.s$ at 77 K and 1,250,000 $cm^2/V.s$ at 5 K for a two-dimensional carrier density of about 3 x 11 cm^{-2} in the heterostructure of GaAs/N-Alx Ga_{1-x} As (x = 0.3). The selectively doped heterostructure was grown on a (100)-oriented, semi-insulating GaAs at 680°C by MBE. The structure consists of a 0.1 μm $Al_{0.3}Ga_{0.7}As$ layer doped with 2×10^{18} cm^{-3} Si, an 200Å undoped $Al_{0.3}Ga_{0.7}As$ spacer-layer and a 0.8 μm undoped GaAs layer. The AlAs mole fraction, x = 0.3, was chosen because they find the highest mobility for x = 0.3.

When irradiated with light, the 2DEG mobility increased to 2,120,000 $cm^2/V.s$ with Ns = 50.4×10^{11} cm^{-2}. This is the highest mobility ever reported in any semiconductor material system. The dependence of the 2DEG mobility on the spacer-layer thickness was also studied carefully by Fujitsu workers. In the spacer-layer thickness range of 0-200Å, they found that the 2DEG mobility increased monotonically with an increasing spacer-layer thickness.

In the MITI-sponsored project, particular emphasis is placed on:

- the growth of highly uniform, large diameter, three-inch, HEMT layers,

- the layers with high 2DEG mobilities, and

- the surface-defect free layers by MBE.

By optimizing the source cell-substrate distance, the cell opening and the cell opening angle, highly uniform n-$Al_{0.28}Ga_{0.72}As$ layers were grown on a three-inch diameter GaAs substrate. The layers were grown at the substrate temperature of 680°C rotated at 15 rpm. Within the diameter of 70 mm, the thickness and carrier density of the epitaxial layers are controlled within ±1%. Thus, improvements in an area of four times the previous area were attained. For the heterostructure consisting of an 800Å undoped GaAs, 60 Å undoped AlGaAs spacer, 900 Å n-$Al_{0.28}Ga_{0.72}$ As layer, and 100 Å n-GaAs cap layer, the distribution of sheet carrier concentrations and 2DEG mobilities within the diameter of 70 mm was uniform within ±2%. Mean values of the 2DEG mobility and the sheet carrier concentration are μ = 112,000 $cm^2/V.s$ and n_s= 5.8×10^{11} cm^{-2} at 77 K respectively.

At Fujitsu, continuing efforts are being expanded to reduce the surface defects--called "oval defects" on MBE grown layers. By using TEM and SEM, they were able to classify the surface defects into three types--A, B, and C according to defect areas; A ≈ 100 μm^2, B ≈ 10 μm^2 and C ≈< μm^2.

Types A and B are the oval defects resulting from Ga droplets and type C is being identified to result from microdefects generated because of substrate dislocations and flatness. With careful control of Ga-source loading conditions, growth parameters and processes, and with the use of dislocation-free substrates, they were able to reduce the 100 μm^2 A defects below 100 cm^{-2}.

Chip yields of HEMT devices influenced by surface defect densities as a function of total HEMT gate areas in a chip were calculated by Fujitsu workers. It was shown that for a 4 K level LSI SRAM, the chip having the surface defect density of 100 cm^{-2} yields about 70% functional HEMTs, while for a 16 K-level LSI SRAM, it will be necessary to reduce the surface density below 10-100 cm^{-2}.

- Process Technology

Recently, Fujitsu has fabricated a low noise HEMT with a 0.4 μm gate length which yielded a noise figure of 1.08 dB and an associated gain of 12.7 dB at 12 GHz at room temperature. At 20 GHz, the HEMT gave a noise figure of 1.7 dB and an associated gain of 8.8 dB at 20 GHz performance of the HEMT which is equivalent to the best result reported for a 0.25 μm gate GaAs MESFET.

In order to produce a short gate length and a low source resistance which plays an important role in a device noise figure, Fujitsu's approach was to employ the recessed self-aligned gate technique with a combination of direct electron beam lithography and selective dry etching.

The HEMT structure consists of a two-inch-diameter, semi-insulating GaAs substrate, undoped GaAs, 200 Å 2×10^{18} cm^{-3} Si-doped n-type $Al_{0.3}Ga_{0.7}As$, 300 Å n-type, graded AlGaAs, and 500 Å n-type GaAs cap layer grown at 680°C. The graded n-AlGaAs with a gradually changing mole fraction of AlAs was added to

reduce source resistance by eliminating the discontinuity of the conduction bands between n-AlGaAs and n-GaAs. The undoped AlGaAs spacer-layer was not employed in order to obtain a high sheet carrier concentration and low sheet resistance. The 2DEG mobilities of ∿6000 $cm^2/V.s$ at 77 K were measured.

A HEMT having a 0.4 μm gate length and 200 μm gate width, and a channel length of 1.6 μm was fabricated by the following process. First, the mesas were formed by wet chemical etching. Then, after defining source and drain contact areas by photolithography, AuGe/Au ohmic contacts were alloyed at 450°C and the gate areas were delineated by direct electron beam lithography.

For the self-aligned gate structure, the gate region was recessed using the selective dry etching technique instead of the wet chemical etching technique. The selective etching technique utilizes a CCL_2 F_2 + H_2 gas discharge and it removes the GaAs cap layer selectively. For example, the etching rate of $Al_{0.3}Ga_{0.7}As$ is about 20 Å/min against the etching rate of 5200 Å/min for GaAs at a self-generated bias voltage of 140 V, giving the selectivity ratio of 260. Following the removal of the GaAs layer in the gate region, the Al gate metal was evaporated and lifted off using the resist mask of the dry etching process and self-aligned to the n-GaAs cap layer. When compared with the 0.5 μm recessed, wet-etched gate devices, the self-aligned gate devices provided lower source resistance (from 4 Ω to 2.5 Ω) and a noise figure of 1.08 dB versus 2.5 dB at 12 GHz.

Using the self-aligned fabrication technology, Fujitsu is advancing the HEMT technology for logic and memory LSI circuit applications.

For an inverter in the DCFL circuit configuration, a self-aligned structure of enhancement-mode (E) and depletion-mode (D) HEMT was formed. The basic epitaxial layer heterostructure grown by MBE is similar to the one used for the low noise HEMT as described before, except that a very thin $Al_{0.3}Ga_{0.7}As$ layer was embedded in the two n-GaAs cap layers to serve as a etching stopper against the selective dry etching as shown in Figure 1. In this way, they were able to achieve precise control of the gate recessing process for both E- and D-HEMTs using selective dry etching. After the mesa etching, AuGe/Au ohmic contacts were alloyed for both E- and D-HEMTs. Then gate patterns for E-HEMTs were formed and the top GaAs Cap layer and the $Al_{0.3}Ga_{0.7}As$ stopper were removed by wet etching. The formation of gate patterns for D-HEMTs was followed using the same resist. By applying selective dry etching, the top GaAs cap layer was removed for D-HEMTs and the second GaAs cap layer below the $Al_{0.3}Ga_{0.7}As$ was etched away for E-HEMTs. For the self-aligned Schottky gates, Al was deposited.

Detailed investigations of the selective dry etching technique, however, shows that damages are introduced as a result of dry etching, which effects transconductances and threshold voltages of HEMTs. The transconductances of the HEMT is decreased and the threshold voltage is increased with an increase in the self-generated bias voltage in the gas discharge. Therefore, the optimization of dry etching conditions was necessary to minimize the damage introduced by the process. It was found that both transconductance and threshold voltage were restored and stabilized after annealing at 400°C up to the self-generated voltage of ∿240 V.

Histograms of threshold voltage uniformities for 1 μm gate E- and D-HEMTs distributed over two-inch wafers are shown in Figure 2. The standard deviations in

threshold voltages (σ) are σ = 16 mV at V_T = 0.092 V for E-HEMTs and σ = 24 mV at V_T = -0.931 V for D-HEMTs. For an area of 10 mm x 10 mm, σ = 6 mV at V_T = 0.040 V for E-HEMTS and σ = 11 mV at V_T = -1.14V for D-HEMTs are measured. The ratio of the standard deviation of 16 mV for E-HEMTs to the logic swing (0.5 V for DCFL) is only 3%. These results demonstrate the viability of HEMT technologies for realization of ICs with LSI/VLSI-level complexities.

The HEMT 1 Kb SRAM is being developed using 1.5 μm gate devices with 3 μm design rule technology. The SRAM, which has been designed to operate with an access time of 0.87 ns with a power dissipation of 360 mW at 77 K, has 7244 devices in a chip size of 3.0 mm x 2.9 mm. The memory cell consisting of a six-transistor cross-coupled flip-flop circuit with five devices has a dimension of 55 μm x 39 μm.

The HEMT 4 Kb SRAM operating with an access time of 2.0 ns with a power dissipation of 1.6 W at 77 K are also being designed with the same device technology as employed in the 1 Kb SRAM. A total of 26,864 E/D HEMTs are integrated in a chip of 4.76 mm x 4.35 mm. The configuration and dimension of the memory cell is the same as in the 1 Kb SRAM.

- Implantation and Annealing

As an alternative means of forming n-active layers or n^+-highly doped layers for ohmic contacts, implantation into an AlGaAs/GaAs heterostructure is being systematically examined at Fujitsu. The annealing, particularly short-time lamp annealing, characteristics of the selectively doped and ion implanted heterostructures are being investigated.

The ion implantation of Se into MBE grown, undoped AlGaAs is being conducted to form highly doped n-layers. Considerable implantation damage was observed in electrical profiles in the vicinity of the projected range for the samples implanted at room temperature even after lamp annealing at 1000°C, 10 s. Hot implantation or multiple implantation at a low dose was necessary to reduce the amount of the implantation damage. In order to study the redistribution of the doped Si atoms in the AlGaAs during annealing, short-time lamp annealing using a tungsten-halogen lamp was also carried out on selectively-doped (SD) GaAs/N-AlGaAs grown by MBE. At the 900°C, 20 s annealing, very little changes in the electron mobility and the electron concentration of the two-dimensional electron gas (2DEG) were observed in contrast to the conventional furnace annealing. The electron mobility and concentration at 77 K remained very high, 74,000 $cm^2/V.s$ and 4.8 x 10^{11} cm^{-2}, respectively, which are 73% and 94% of the "as grown" samples. Therefore, for heterostructure material, lamp annealing can be adopted effectively for contact processing and damage annealing of ion implanted samples. However, no serious efforts in the application of both implantation and lamp annealing to actual device fabrication of HEMT devices was detected.

SUMMARY

In this report, an attempt was made to depict some intensive efforts in the development of HEMT LSI technology going on at the Fujitsu Laboratories at Atsugi. The efforts are intensive because Fujitsu firmly believes that, beyond Si-based technology, GaAs LSI, particularly HEMT LSI, is the key technology for future high speed supercomputers. With Si-based technology, it will be difficult to meet the performance

requirements of a computer at a speed of 10 Gflops.

The HEMT technology, which has been explored at Fujitsu, has opened many new possibilities for LSI/VLSI applications with regard to high speed performances. The HEMT frequency divider circuits operating at the maximum clock frequency of 8.9 GHz with a 2.8 mW/gate power dissipation at 77 K corresponds to a logic delay of 22 ps/gate. This speed is three times faster than that achieved with the GaAs MESFET technology. Fujitsu believes that with 0.5 μm design rule 10 K-gate HEMT LSI technologies, computer performance of over 120 MIPS with a system clock cycle time of 2 ns will be achieved.

The 4 Kb HEMT SRAM with an address access time of 2.0 ns at a power dissipation of 1.6 W at 77 K fabricated by Fujitsu using 1.5 μm devices and a 3 μm design rule is the highest speed reported for 4 Kb RAMs.

In order to attain the goals of the supercomputer projects, scientists and engineers at Fujitsu are constantly striving to improve material quality and process technologies and to increase yields and reliability of LSI circuits.

Fujitsu's achievements in science and technology are impressive. At Atsugi, truly creative and innovative research which seeds future technologies is encouraged.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation and thanks to Dr. Takahiko Misugi, director of Fujitsu Laboratories, Ltd., Atsugi, who provided considerable assistance and useful advice regarding liaison activities in Japan. He also provided technical information and arranged meetings with many investigators during my visits to Fujitsu. I am especially indebted to Dr. Masayuki Abe, section manager, the Compound Semiconductor Devices Laboratory, who provided me much of the data used in this report and to all the scientists (see Appendix II) who participated in the discussions for their generous time and hospitality.

APPENDIX I

OUTLINE OF FUJITSU LABORATORIES

History

1962	Established as a research group for Fujitsu Limited's R&D divisions
1968	Officially established as an independent research institute
1983	Opening of Fujitsu Laboratories, Atsugi, in Mori-no-sato, Atsugi

Capital

3 billion yen

Employees 1,230

Fujitsu Laboratories, Kawasaki:	630
Fujitsu Laboratories, Atsugi:	600

Fujitsu Laboratories, Atsugi facilities

Site: 71,800 m²
Buildings: 26,700 m², including 5,500 m² of clean rooms
. tennis club (clubhouse, two courts)
. parking (245 vehicles)

Organization
Fujitsu Laboratories, Ltd.
President: Bunichi Oguchi

-Administration Division
-R&D Planning and Technical Relations

Fujitsu Laboratories, Kawasaki
Managing Director: Kohichi Endo

-Six R&D Divisions

Fujitsu Laboratories, Atsugi
Director: Kaneyuki Kurokawa

-Administration Department
-R&D Coordination Office
-Exploratory Devices Development Division
-Semiconductor Division
-Components and Sensing Technology Division
-Materials Division

APPENDIX II

Listed below are the individuals at Fujitsu who provided information discussed and their specific areas of interest:

T. Misugi	Director, Fujitsu Laboratories, Ltd. Atsugi	Overview of Fujitsu's R&D activities
M. Abe	Section Manager, Compound Semiconductor Devices Laboratory I	HEMT LSI technology
T. Mimura	Principal Researcher, Compound Semiconductor Devices Laboratory I	HEMT device technology
S. Hiyamizu	Section Manager, Semiconductor Materials Laboratory	MBE material growth
H. Nishi	Section Manager Compound Semiconductor Devices Laboratory II	Processing technology

Location: Fujitsu Laboratories, Ltd., Atsugi
1677 Ono, Atsugi 243-01, Japan
Tel: (0462) 48-3111

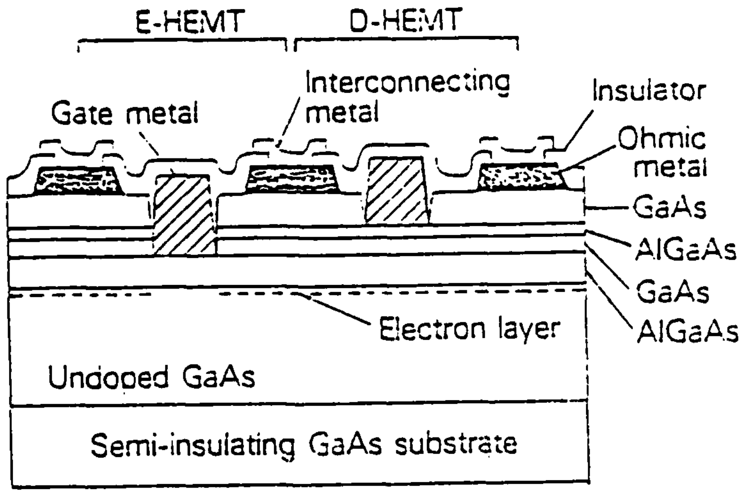

Figure 1. The self-aligned E/D HEMTS forming an inverter in DCFL circuit configuration

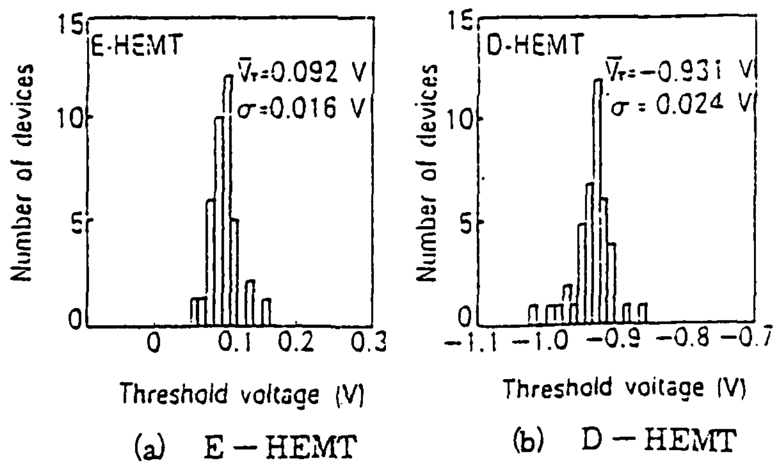

Figure 2. Histograms of threshold voltage uniformities E- and D-HEMTS distributed over two-inch wafers

These figures are provided through the courtesy of M. Abe.

JAPANESE ACTIVITIES IN MONOLITHIC INTEGRATION OF III-V COMPOUND SEMICONDUCTORS AND SILICON

Yoon Soo Park

INTRODUCTION

There appears to be a growing interest in Japan to develop integrated circuits on the same chip by monolithically integrating GaAs or other III-V compound semiconductors and Si. Efforts to grow III-V compound semiconductors on Si substrates stem from the desire to take full advantage of the unique device characteristics of both III-V materials and Si for the development of optoelectronic ICs and 3D devices. By utilizing inexpensive, high-quality Si substrates low-cost production of ultimate devices can also be expected.

At the recent spring meeting of the Japan Society of Applied Physics held in Tokyo on 29 March-1 April 1985, a number of papers pertaining to research on the growth of GaAs or other related material systems on Si and the fabrication of devices based on the GaAs/Si structure were detected. Institutions that are actively engaged in the research and development work of such materials systems are:

- Oki Electric Industry Company, Ltd.,
- the Musashino Electrical Communication Laboratory of NTT,
- the Namba Laboratory of Osaka University,
- Nagoya Institute of Technology,
  Nagoya University,
- the LSI Research and Development Laboratory of Mitsubishi Electric Corporation,
- the Electrotechnical Laboratory, and
- the University of Electrocommunications.

Of all the institutions participating in this research, efforts at the Research Laboratory of Oki Electric Industry Company being conducted under the subproject, Three-dimensional ICs in the Future Electron Device portion of the Research and Development Project of the Basic Technology for Future Industries, a program which is sponsored by the Agency of Industrial Science and Technology, (MITI), appears to be the most extensive in scope involving materials and device development activities. A review of the current status of activities at Oki was presented at the Fourth Symposium on Future Electron Devices held in Tokyo on 4-5 July 1985.

This report attempts to summarize current activities in the monolithic integration of GaAs or other related material systems in Japan.

RESEARCH ACTIVITIES

. Oki Electrical Industry Company, Ltd.,
  Research Laboratory
  550-5 Higashiasakawa
  Hachioji, Tokyo 193

  Researchers: Dr. K. Kaminishi
  Dr. C. Yamaguchi
  Dr. M. Akiyama

Until recently, Oki had been growing GaAs epitaxial layers on Si substrates using Ge layers as the buffer layers--Ge-coated Si substrates--to relax the lattice mismatch between GaAs and Si (∿4%). They had demonstrated the feasibility of fabricating FETs and ring oscillators using GaAs/Ge/Si systems. Lately, however, they have succeeded in growing single domain GaAs layers with a mirrorlike surface by MOCVD on (100)-oriented Si/substrates without the Ge buffer, and have fabricated GaAs MESFETs and ring oscillators with good characteristics.

For growth they are employing a horizontal, low pressure (∿90 Torr) MOCVD reactor, using TMG and AsH_3 as source materials at the total flow rate of 2000 SCCM. To obtain a single domain GaAs layer, careful surface cleaning procedures were necessary by heat treating the substrate at above 900°C for 10 minutes in the flow of H_2 and AsH_3. Then, after cooling the substrate to 45°C or below, a thin GaAs layer of ∿200 Å was grown. The growth of the second GaAs layer was carried out at the conventional growth temperature of 700-750°C. By employing such two-step growth procedures, Oki workers were able to obtain good quality GaAs layers with a room temperature mobility of 5200 $cm^2/V.s$ and a carrier concentration of 1×10^{16} cm^{-3}.

To fabricate MESFETs and ring oscillators, a 1.0 μm thick GaAs was first grown on a two-inch n^+-Si(100) wafer by the two-step growth procedure as described above. Then, a 1.8 μm thick, vanadium (V)-doped, semi-insulating GaAs layer and a 1.0 μm thick, undoped GaAs wafer was successively grown. A MESFET with a 1 μm x 10 μm gate was formed on the top undoped GaAs layer by the W-Al gate self-alignment process in combination with direct ion implantation for channel and n^+-ohmic contact region formation. For the channel regions of E- and D-MESFETs, a ^{29}Si dose of (1.1-1.3) x 10^{12} cm^{-2} and (2.0-2.2) x 10^{12} cm^{-2} at 60 keV was employed respectively. Following the W-Al gate metallization and the implantation of the n^+-regions at a dose of 1.5×10^{13} cm^{-2} at 100 keV, the structure was annealed in a $AsH_3/H_2/Ar$ atmosphere without a cap. The source and drain ohmic contacts were formed by deposition and alloying of AuGe/Ni/Au. The fabricated MESFET showed a transconductance of 200 mS/mm.

Using similar fabrication procedures, they also fabricated a 17-stage ring oscillator with E- and D-MESFETs of a 1.0 μm x 2.0 μm gate having a minimum propagation delay time of 51 ps/gate at a power dissipation of 1.1 mW/gate which is comparable to conventional GaAs MESFET characteristics. The 17-stage ring oscillator fabricated on the GaAs/Si structure showed better performance data than that obtained on the GaAs/Ge/Si structure. The results obtained by Oki are encouraging and demonstrate the potentiality of fabricating GaAs devices on large and low-cost Si substrates.

In pursuit of developing three-dimensional devices, Oki also is conducting experiments to grow GaAs on SiO_2 layers through a Ge interlayer. They are growing Ge layers over SiO_2 using the zone melting recrystallization technique (ZMR), in which a single crystalline SrF_2 is used as a seed for the ZMR of Ge films. To form a Ge SOI structure, first a 1000 Å-thick SrF_2 film was evaporated on a (100) GaAs substrate at 400°C. After depositing a 500 Å-thick CVD-SiO_2, a seeding region of 40 μm x 10 μm was opened and a 1 μm-thick Ge film was vaporized using an electron beam. The zone melting recrystallization was performed using a 1.6 mm strip heater heated at 1600-1800°C at a speed of 1.6 mm/s over the Ge film with a sputtered W-cap. During the zone melting, the substrate was maintained at 800°C. Laterally

recrystallized Ge films over the SiO_2 layer exhibited good crystallinity.

By combining the two-step growth and Ge SOI techniques, Oki has recently grown a layered structure containing two GaAs layers. The layered structure consists of a Si substrate, MOCVED grown GaAs layer, SrF_2 crystalline film, SiO_2 film with seed openings, ZMR Ge layer and MOCVD GaAs layer. Though the surface morphology of the second GaAs layer was not of device quality, improvements in the crystal quality is anticipated by the further optimization of growth conditions and morphology of ZMR Ge layers.

. The Musashino Electrical Communication Laboratory, NTT
Musashino-shi, Tokyo 180

Researcher: Dr. Y. Ohmachi

Because of a small lattice mismatch of Ge with GaAs ($\sim$0.07%), researchers at the Musashino ECL prefer to grow GaAs on SiO_2-coated Si (SiO_2/Si) through a Ge interlayer. Their device quality configuration actually is made of GaAs-W-Ge-W-SiO_2-Si layers. After coating Si (100) wafers with a 0.2 μm-thick, thermal SiO_2 layer, a thin ($\sim$400 Å), tungsten (W) layer is deposited over the SiO_2 coating prior to Ge deposition as a buffer layer and on top of the evaporated Ge as a cap for the zone melting. The W-buffer layer is believed to facilitate the wetting of the Ge melt to the SiO_2 coating and to prevent a molten Ge agglomeration. The use of the W-cap layer is necessary to promote a flat, large-area growth of Ge.

To form the crystal seed for the Ge recrystallization of a molten zone, the sample is patterned to expose the Si substrate by photolithography and wet etching. Then, Ge (0.4-0.5 μm) and W (300-500 Å) layers are successively deposited. For recrystallization, a rf-zone-heating slider system is employed, in which the substrate holder moves across the graphite heater. The crystallization moves on by lateral epitaxy by the seed solidification (LESS) process.

After the Ge recrystallization, GaAs layers are grown for device fabrication. For GaAs growth, the Musashino ECL is employing a conventional atmospheric pressure MOCVD system. GaAs layers are grown at 650°C using TMG and AsH_3 (5% in H_2) as source gases and H_2Se and DEZ as dopant sources for n- and p-type doping respectively. After removing the W-cap layer, a GaAs structure consisting of n-GaAs, p-GaAs and p^+ GaAs are successively grown.

They have fabricated LEDs from the above structure, which operates at 3-4 V and 40-50 mA. The LED emits light at the wavelength of 8870 Å which is slightly longer than the wavelength of 8750 Å emitted in a homoepitaxial device. They attribute this energy shift to the energy gap shift of the tensile strain in GaAs which is caused by residual stress in Ge, generated during the recrystallization process at the solidification temperature and followed by a differential thermal contraction. Researchers at the Musashino ECL currently are involved with studying recrystallization mechanisms and with characterizing the recrystallized Ge crystals.

. Osaka University
The Namba Laboratory
Toyonaka-shi, Osaka

Researchers: Profe sor S. Namba
Dr. M. Takai

The approach taken at the Namba Laboratory is different from that taken by the Musashino Electrical Communication Laboratory, NTT, where they have deposited Ge on a W-layered coated SiO_2 ($Ge/W/SiO_2$). The Namba group claims it is not necessary to insert the W-layer for good growth of Ge if the SiO_2 is of high quality.

To realize GaAs-on-insulator (GaAs SOI), the laboratory has succeeded in growing single crystalline Ge islands with (100) orientation on insulating substrates (SiO_2/Si) by zone melting with graphite strip heaters. GaAs layers are being grown by MBE.

Two very interesting types of geometrical patterns for Ge islands were used. One of the patterns consists of a series of 100 x 80 μm rectangles with sides connected to a narrow, 30 x 10 μm stripe which selects and transfers a single grain orientation during melt zone movement and suppresses subboundary formation in the connected islands. The second type is a series of isolated 250 x 100 μm rectangles with a peaked side. A single crystal grows from the peak on the peak side as a self-seed and the melt zone is moved from this side. The Ge islands grown after zone melting were found to be single crystals with <100 > orientations and had electron concentrations of 10^{16}-10^{18} cm^{-3} and Hall mobilities of 1-3 x 10^{3} cm^{-2}/V.s.

The GaAs layers grown by MBE on these islands were of good quality as evaluated by optical microscopy and photoluminescence. The layers exhibited photoluminescence spectra similar to those of GaAs layers grown on bulk Ge crystals, comparable in their intensities but slightly shifting in peak energies due to the strain induced by the thermal expansion coefficients between Ge and GaAs.

. The Electrotechnical Laboratory (ETL)
Electronic Device Division
1-1-4 Umezono, Sakura-mura
Niihari-gun, Ibaraki 305

Researchers: Dr. Y. Hayashi
Dr. H. Kawanami
Dr. K. Nagai
Dr. T. Sakamoto
Dr. E. Suzuki

The Electrotechnical Laboratory (ETL) at Tsukuba Science City is conducting research on basic technology for optical I/O Si ICs in support of the MITI-sponsored large-scale project, entitled "Optical Measurement and Control System," (the optoelectronic project). In this research task, efforts are being expanded to develop a basic technology to integrate new electrooptic devices with silicon signal processing devices on silicon substrates. The aim of the research is to link optical transmission lines through an electrooptic device with optical input/output (I/O) interface.

To obtain light emitting and detecting devices on a Si substrate, MBE

technology is being employed. Specifically, GaP epitaxial layers as light emitting material and silicon multilayers as light detectors are grown on a Si substrate. Heteroepitaxy growth of GaP on Si is chosen, because of negligible lattice mismatch between GaP and Si (A_{Si} = 5.4309 Å and A_{GaP} = 5.4495 Å).

Recent accomplishments include:

- establishment of Si surface cleaning at a temperature of 800°C,
- formation of ohmic contacts to n- and p-GaP by laser annealing,
- growth of GaP films on a Si substrate at growth temperatures as low as 300°C,
- growth of a Si multilayer n-p-structure. Also, 80 periodic layers of 260 Å in thickness have been grown; p-type layers were obtained by Ga-doping and n-type layers by Sb-doping.

. Nagoya Institute of Technology
Laboratory of Semiconductor Electronics
Gokiso-cho, Showa-ku
Nagoya 466

Researchers: Professor M. Umeno
Dr. S. Sakai

. Nagoya University
Department of Electronics
Gokiso-cho, Showa-ku
Nagoya 466

Researchers: Professor S. Hattori
Dr. T. Soga

The Laboratory of Semiconductor Electronics of the Nagoya Institute of Technology in collaboration with a group at Nagoya University is involved in a strong MOCVD growth program. Their growth program includes the MOCVD growth of AlGaAs and GaAs on GaAs, Si or Ge substrates, and of GaP on Si substrates leading to the fabrication of solar cells, LEDs, LDs and optoelectronic ICs.

Their scheme for the GaAs growth on Si is to insert interlayers of materials such as AlP, GaP, AlGaP, or GaAsP, whose lattice constants closely match with the lattice constant of Si between GaAs and substrates. The final structure they have examined recently consists of Si → AlP → AlGaP → GaP/GaAsP SL → GaAsP/GaAs SL → GaAs. The idea is to relax the lattice mismatch by a strained superlattice.

The layers are grown on a Sb-doped (100) Si substrate at atmospheric pressure in a horizontal MOCVD system using TMG, TMA, AsH_3 and PH_3 as source gases. Before the initiation of the layer growth, the Si substrate is heated at 1000°C for about 10 min to remove SiO_2 at the surface. The intermediate layers are grown at temperatures of 830-950°C and the top GaAs layer is grown at 730°C. Each

superlattice layer consists of 10 layers of 170 Å in thickness, and the thickness of AlP + AlGaP is varied to keep the thickness ratio of AlP/AlGaP at 0.5. When the GaAs layer grown on the superlattice structure was examined by C-V and photoluminescence measurements, both carrier concentrations and the PL intensity normalized against the carrier density decreased with an increase in the thickness of AlP + AlGaP. However, there appeared to be a maximum value in the normalized photoluminescence intensity. The best PL intensity value for the GaAs, so far obtained, is about 56% of the GaAs layer grown on a GaAs substrate.

The Nagoya group is currently pursuing fabrication of a AlGaAs/GaAs layer diode on Si. They are developing a technique to form a V-grooved cavity in Si substrates by the cleavage and etching technique.

. Mitsubishi Electric Corporation
LSI Research and Development Laboratory
4-1 Mizuhara, Itami
Hyogo 664

Researcher: N. Yoshihara

The LSI Research and Development Laboratory of Mitsubishi Electric Corporation at Itami recently reported the initial results of their efforts on the fabrication of GaAs devices on Si. Their efforts included the formation of a n-AlGaAs/GaAs heterostructure on a Si substrate by MBE. After heat-treating a p-type Si for an hour at 800°C in the substrate holder, epitaxial growth was initiated. The MBE grown structure consisted of a 500 Å GaAs primary buffer layer, 0.4 μm second buffer layer, a 0.2 μm GaAs/AlGaAs superlattice buffer layer, a 1.5 μm undoped GaAs layer, a 30 Å AlGaAs spacer, a 400 Å n-AlGaAs layer, and a 150 Å GaAs layer.

For the structure, two-dimensional electron gas mobilities of 4000 $cm^2/V.s$ and 36,000 $cm^2/V.s$ were obtained at 300 and 77 K, respectively. A trial MESFET having 9.0 μm gate length and 314 μm gate width exhibited a Gm of 67 mS/mm.

. The University of Electrocommunications
Department of Communications Engineering
1-5-1 Chofugaoka
Chofushi, Tokyo

Researcher: Professor K. Okamoto

A group led by Professor Okamoto at the University of Electrocommunications is also actively working on the growth and characterization of the GaAs/Ge/Si system. They are growing GaAs on Si through a Ge interlayer by MOCVD. By monitoring a shift in the peak position and a variation in the intensity of photoluminescence of the GaAs layer grown on Ge/Si, they are optimizing the thickness of grown layers which does not exhibit cracks or strain. They find no cracks in about 3-μm-thick GaAs layers. Also they find that a better quality of GaAs can be grown on annealed Ge/Si substrates.

Because of nearly equivalent thermal expansion coefficients between molybdenum (5.1×10^{-6} C^{-1}) and GaAs (5.8×10^{-6} C^{-1}), Mo was tried as an

intermediate layer to grow GaAs. The GaAs layers grown on Mo/Si substrates by MOCVD were polycrystalline. However, when the layers were annealed by a Q-switched ruby laser in methanol, the recrystallization of the deposited GaAs layers was observed. Also, when the samples were annealed in $SnCl_2$--dissolved methanol the samples were doped effectively showing high conductivity.

SUMMARY

In this report, an attempt was made to summarize Japanese activities in monolithic integration of III-V compound semiconductors and silicon; the research along this line has long-range goals and is of an exploratory nature. However, the outcome and payoffs of the efforts will have a great impact on the realization of optoelectronic ICs and 3D devices.

In the U.S.A., similar efforts are being carried out at MIT, IBM, and Cornell University. More and more institutions seem to be interested in this research. An example is the latest accession of the LSI Research and Development Laboratory which Mitsubishi Electric Corporation has added to their existing activities. Japanese activities in this area should be carefully followed.

GaAs BULK CRYSTAL ACTIVITIES IN JAPAN REVISITED

Howard Lessoff and Yoon Soo Park

INTRODUCTION

In 1984, Yoon Soo Park made a survey of GaAs bulk crystal growth technology which appeared in the ONRFE *Scientific Bulletin 9*, (3) 65, (1984). Since that report with the increase in gallium arsenide devices and ICs, the need for high quality bulk semi-insulating wafers has become more acute. The amount and the intensity of work on crystal growth has increased in order to develop GaAs wafers having the equivalent quality available in silicon wafers. As a result of this emphasis, a relook at the technology of GaAs crystal growth in Japan was undertaken. Although the number of companies growing GaAs single crystals is quite large, the current revision is a result of meetings at five Japanese facilities: the Optoelectronics Joint Research Laboratory, Nippon Telegraph and Telephone Corporation (NTT), Atsugi Electrical Communication Laboratory, Toshiba Research and Development Center, NEC Corporation, Fundamental Research Laboratories, and Sumitomo Electric Industries, Ltd., Semiconductor Division. Each of these laboratories has a particular point of view in addressing the bulk GaAs technology.

The Optoelectronic Joint Research Laboratory was set up by the Ministry of International Trade and Industry (MITI) for fundamental growth of GaAs, characterization and epitaxial growth of III-V compound semiconductors by MBE and MOCVD. Sumitomo Electric is probably the largest producer of GaAs single crystals. Toshiba Corporation has a research program in the growth of GaAs using the vertical heater method. NEC has no major bulk growth capability, but is a user of GaAs wafers for high speed MODFETs and superlattice devices. NTT performs experimental and developmental crystal growth as well as device and integrated GaAs circuit research.

- Optoelectronics Joint Research Laboratory (Dr. T. Fukuda)

The Optoelectronics Joint Research Laboratory (OJRL) was founded in 1981 in order to help establish the integrated optoelectronic technology in Japan. The laboratory was a joint effort by MITI and nine members of industry. The industrial members are Fujitsu, Furukawa, Hitachi, Matsushita, Mitsubishi, NEC, Oki, Sumitomo, and Toshiba. The laboratory was set up for five years and is expected to terminate in 1986. The technical director of the laboratory is Dr. Izuo Hayashi, known for work on heterojunction lasers and the director general is Takashi Izuka.

The major areas of research are:

- bulk growth of single crystal GaAs,
- advanced methods for crystal characterization, and
- new epitaxial growth technology including fabrication methods by ion beams.

The funding for equipment has been approximately three billion yen ($14 million). The laboratory is extremely well equipped including such items as a number of high pressure LEC furnaces, molecular beam epitaxial systems and metal-organic growth systems. The technical output of the laboratory has been quite impressive. In 1983, there was a total of 138 publications and in 1984, a total of 153.

In the areas of bulk crystal growth, the goal is to achieve uniform wafers of undoped

semi-insulating gallium arsenide having low defect density. The main growth method is liquid encapsulated Czochralski growth. Among the experimental methods under investigation include the use of a magnetic field (both vertical and horizontal superconducting magnetics are employed), reduction of temperature gradients at the liquid/solid interface, and maintaining the crystal in a controlled temperature environment after pulling through the boric oxide encapsulant. There is very limited work on In doping to reduce the etch pit density (EPD) since the OJRL feels that slice-to-slice yield will be limited and there are slight changes in lattice parameters for each wafer with the In doping. These slight changes in lattice parameters cause interfacial strains if subsequent epitaxial layers are grown on the substrates.

By using a graphite cap having boric oxide seals surrounding the PBN crucible and an extended heater, they have succeeded in reducing the temperature gradient to about 20° /cm at 20 atm arsenic overpressure during growth. The growth is monitored via x-rays so that a sight port is not used since such a port would change the thermal profile. The EPD has been reduced to about 10^3 /cm² for two-inch-diameter crystals pulled in the (100) direction. In order to further improve the control of stochiometry and hence resistivity, they have used an arsenic injection technique, where arsenic vapor is injected into the melt during the pulling. The arsenic is in a small vial above the edge of the crucible with an injection tube going into the melt. The pull rate is about 9 mm /hour.

This method has yielded high resistivity GaAs; further improvements in compositional uniformity are feasible by the application of a magnetic field during growth. The field apparently reduces the striations by creating a uniform liquid/solid interface temperature but does not appear to effect the EPD. The group has looked at isoelectronic doping with indium for additional reduction in EPD. They have achieved near zero EPD using the same techniques that yielded an EPD of about 10^3/cm² by In doping, but only part of the boule is usable since the distribution coefficient of In is much less than one (1) and therefore the melt increases in In concentration with the growth. With the increasing In concentration the single crystal boule will go polycrystalline after about 50% of the melt is pulled. In order to compensate the low distribution coefficient of In, attempts have been made to double-dope GaAs. For n-type material, In at 1×10^{20} and Si at 1×10^{18} has been used. About 70% of the pull is usable. For p-type material, 1×10^{20} In and 1×10^{19} Zn is used with about 50% of the pull being usable. If a high magnetic field is used during the pull of the doped GaAs then the distribution coefficient for the dopant is slightly changed.

The group has not been able to correlate the properties of MESFETs with EPD as reported earlier by a different laboratory. Indeed the OJRL has found the FET properties appear independent of the EPD when the etch pits are fairly uniformly distributed and low in concentration ($<10^4$/cm²). In summary, some of their achievements in bulk growth include:

- control of melt composition by As injection during growth,
- automatic diameter control of crystals up to five inches in diameter to within 1.5%,
- the use of magnetic fields to reduce striations and control uniformity of defects such as EL2 and impurities,
- growth of undoped semi-insulating GaAs two-inch-diameter crystals having an EPD of about 10^3/cm² by control of temperature gradients at the liquid solid interface, and
- using an 850°C anneal of the crystal to improve uniformity in a wafer.

In the area of substrate characterization, the group has not seen the linear effect of

EL2 with the absorption coefficient at 1.1 μm and has found that the EL2 concentration by DLTS does not correlate with the etch pit density. They find three levels of the so-called EL2 which they name EO1, 2 and 3. The EO3 is higher near dislocations, but EO1 and 2 appear independent of the dislocation density. The EO1 appears to be related to the so-called EL2 and they are not able to correlate EO1, 2 or 3 with the oxygen content.

In the MOCVD growth, a low pressure system is employed operating at 0.1 Torr and as a source, triethylgallium. It is believed that the use of triethylgallium reduces the carbon incorporation in the epitaxial layers. One of the experimental molecular beam epitaxial units is fitted with an excimer laser (lambda physics) for studies of photoexcited deposition.

Other areas of the laboratory are excellently equipped in both quality of items as well as quantity. Included are extensive capability in MBE, MOCVD, and characterization. This major facility is due to terminate in early 1986 with unanswered questions as to what happens to the equipment and the significant capability.

- Toshiba Research and Development Center (Dr. S. Takahashi)

This laboratory is located in the large technology complex of Kawasaki. The facility is quite extensive and the major emphasis is on optoelectronic technology. They have a gallium arsenide growth capability and have stressed LEC growth using a vertical heating technique with heaters not only at the sides of a PBN crucible but also at the base in order to improve the control of the thermal environment.

From an 800 g charge of GaAs and 180 g of B_2O_3 in a four-inch PBN crucible they have achieved two-inch-diameter crystals with an EPD of 10^3 cm^{-2} at the seed end but increasing towards the tail. The pull rate was 9 mm/hr with crucible rotations of 20 rpm and seed at 9 rpm in 20 atm argon. The vertical heating has allowed the thermal gradient to be below 1°C/cm along the solid liquid interface. The suppression of dislocation is believed to be due to the flat growth front.

Toshiba has developed a method of oxidizing the surface of a polished (100) wafer to determine gross etch pit patterns which compare quite favorably with x-ray topograph measurements. The cause of the selective reaction of the gallium arsenide with water at the defects is not understood but a hole/trap model is postulated. The grown oxide film apparently does not contain arsenic. If the gallium arsenide wafer is doped with silicon or magnesium, no patterns are observed. The group has also done some indium and chromium doping. In the case of indium doping no striations are seen in etching, but they are visible by x-ray. For chromium doping, striations are present and what appears to be chromium clustering. They hope that In doping is not necessary since the In concentration will vary from the top to the bottom of the boule and yield of slices per boule will be reduced compared to undoped semi-insulating GaAs.

The use of tungsten nitride produced by reactive sputtering is, according to Toshiba, an excellent layer for self-aligned gate technology. The barrier height is about 0.84 V. Devices have been made with a g_m of 200 mS/mm and an ideality factor "n" is about 1.16. The conditions with the best nitride film growth are: substrates at 800°C and an argon gas stream having 6% nitrogen.

- NEC Corporation, Fundamental Research Laboratories (Dr. H. Watanabe)

This laboratory has LEC growth capability for GaAs, In doped GaAs and are also growing $InAs_xP_{1-x}$. The latter ternary compound is being evaluated for potential applications requiring high mobility at low fields and a high saturation velocity. The group has extensive characterization capability for both bulk crystals and thin films grown by MOCVD and MBE. In the area of LEC growth of GaAs, they have not found a correlation of the EPD with the wafer resistivity but have found correlation with EL2. Both undoped and In-doped GaAs crystals have a very fine precipitate which may be associated with dislocations. Dr. H. Ono has been able to correlate the shape of the etch pit with the indium concentration in semi-insulating In-doped GaAs LEC crystals. By indium doping, EPD as low as 10 to 20/cm^2 has been obtained. There is some striation in the In-doped gallium arsenide, with an increase of the In content at the striations. Devices have been made on the low dislocation In-doped GaAs. The use of the In-doped material has resulted in a greater device uniformity across a wafer and the implantation profiles and activation efficiency appears to be as good as that achieved in undoped semi-insulating GaAs. The implantation is activated by rapid infrared heating and the wafers are capped with silicon oxinitride (Si-O-N). The efficiency of activation is a maximum when the refractive index of Si-O-N is 1.75. The use of indium doping in semi-insulating GaAs is looked on favorably by this group.

It is of interest to note that GaAs varactor diodes are in production at NEC using MBE growth technology. Most of the E/O devices are being grown by the VPE hydride and LPE processes with some devices such as double heterostructure lasers prepared by using both VPE and LPE, the active layer grown by LPE.

- Nippon Telegraph and Telephone Corporation, Atsugi Electrical Communication Laboratory (Dr. S. Miyazawa)

This is a new laboratory with exceptional facilities and equipment. The laboratory specializes in devices and IC research for development for digital and optoelectronic communications from the initial material development thru the preparation of VLSI systems. The material efforts cover both bulk and thin film activities on silicon, III-V compounds and superconductors. The emphasis of the bulk growth of LEC GaAs activities is the use of In to reduce the defect density as determined by EPD. The indium dopant concentration added to the melt is 1 to 5 x 10^{20}/cm^3. The crystal is pulled in a PBN crucible with a thick B_2O_3 encapsulant such that the pulled crystals are always covered by the B_2O_3. This B_2O_3 layer reduces thermal stress in the pulled crystal and is an *in situ* anneal. A vertical magnetic field is also used in order to reduce the striations. During the growth as the crystal is pulled from the melt, it is always encapsulated in the B_2O_3 which reduces sharp temperature gradients. Thus with the limitations of the B_2O_3 depth for visibility and the mechanical problems of the crucible height, the pulled crystals are approximately 2.5 inches long with a two to three-inch-diameter. Only 50% to 60% of the crystal is usable since the distribution coefficient of the In results in excess In in the tail end with precipitation. Thus with these limitations only about 1.25 inches of In-doped GaAs crystal is available for slicing and use as substrates. The use of a defect-free seed is important in order to achieve a defect-free crystal with no central coring. The few slices per growth that are available have been successfully used to prepare digital ICs with good uniformity. Using both the vertical magnetic field and the encapsulation, the electrical uniformity in ICs has been significantly improved compared to the standard LEC growth methods.

In the characterization, NTT has found that the level of EL2 by photoluminescence is higher near the edge of a wafer and a similar increase near dislocations. There are also

stress effects near the vacancies. They postulate that these effects may be due to the reduction of C in arsenic sites near vacancies and also the reduction of C may be related to stress. The use of scanning DLTS indicates that EL2 is nearly uniform at a dislocation although photoluminescence would indicate that EL2 increases.

- Sumitomo Electric Industries, Itami (Dr. S. Akai)

This major production facility was the final laboratory visited in the area of bulk growth of GaAs single crystals. There is a new building completely devoted to the growth, and substrate preparation of GaAs in which there are banks of Bridgman furnaces as well as a large number of automated LEC pullers. There are well-planned clean rooms for growth and material preparation, the majority of the equipment is Japanese made. A plant capability in the future is projected to produce up to 50 tons of gallium arsenide per year. This is up from the current production rate that appears in excess of 10 tons per year. The emphasis in GaAs at the Sumitomo Itami Plant is the development and the production of improved gallium arsenide in bulk crystal form and the preparation of gallium arsenide substrates. Among the items under development are:

- automatic crystal growth in LEC puller,
- use of thermal configuration and dopants such as indium to control EPD,
- experimental use of magnetic fields during LEC growth for increased unformity,
- improvement in Bridgman growth and compounding technology, and
- automated wafer preparation and characterization including cassette handling methods.

They are already marketing In doped LEC GaAs having etch pit densities below 2×10^3 for a two-inch wafer. The etch pit density is determined automatically using a computer microscope which scans an etched wafer. They have found that the threshold voltage for ion implanted MESFETs shifts negatively as the dislocation density increases and that local perturbations in MESFET's can be correlated with cellular structures, slip and lineage in the substrates. The facility has fairly complete characterization capability and is installing both MOCVD and MBE capacity as part of a development effort. The production of InP substrates is being expanded by a factor of about two in order to meet the needs of the optoelectronic market.

SUMMARY AND CONCLUSIONS

The Japanese effort in bulk gallium arsenide is intensive with probably more major LEC crystal pullers devoted to research and development than the entire United States has in production. Various techniques are being addressed to lower the EPD including thermal design, doping and external magnetic fields. The use of indium doping is at present controversial since the yield is reduced and there are questions whether the slight differences in cell size and In doping from wafer-to-wafer will influence device or circuit properties from wafer-to-wafer. Much of the effort is aimed at improving existing technology which may have been theoretically addressed elsewhere, such as the use of magnetic fields and the theory of dislocation formation and thermal conditions rather than the strong theoretical studies which are addressed in other parts of the world. The work overall is of excellent quality with cooperative interactions between organizations at the basic levels via the MITI Laboratories as well as meetings and publications within Japan.

The Japanese laboratories have earlier stressed the use of MBE for quantum well and HEMT-type devices but are rapidly developing MOCVD technology with large emphasis on reagent purity to achieve quality epitaxial layers.

CERAMIC-METAL BONDING RESEARCH IN JAPAN

Thomas W. Eagar

INTRODUCTION

The Japanese call it "ceramic fever," but whatever it is, one cannot help but be impressed with the pervasiveness of research on fine ceramics in Japan. After spending one year visiting well over 50 different *metals* processing laboratories in Japan, it is striking to note that approximately half of these traditionally metals laboratories are now studying ceramic-metal bonding in some form. For example, at the Welding Research Institute of Osaka University, seven out of nine research divisions are working on ceramics of some form whether it be diffusion bonding, plasma spraying, brazing, or laser processing. In the Department of Welding Engineering, at least three out of eight research groups are now working on ceramics. At the Technical Research Center of Hitachi Shipbuilding, ten out of 22 welding researchers are studying ceramics; and the list of examples could continue. No matter what the cause of the fever is, it is catching. Groups not yet studying ceramic-metal bonding at the time of my visit, but with plans to begin in the next year, included Nippon Kokan Steel, Sumitomo Steel, and the Solid State Bonding Research Committee of the Japan Welding Society. The fever is spreading to Korea as well, with several welding laboratories there planning new programs in the next year.

In the review that follows, it should be noted that very little attempt was made to visit or evaluate the ceramic-metal (C-M) research at the many traditional ceramics laboratories. Most of what follows represents new directions for researchers who traditionally have been welding metallurgists. Another factor which should be emphasized is that most of these people have only been studying C-M systems for one to three years; hence, the quantity of results does not yet match the effort level. We can expect to see a significant increase in results within the next two or three years.

SPECIFIC RESEARCH PROJECTS

Dr. S. Kitahara of the National Research Institute for Metals (NRIM) has studied plasma spraying for nearly 20 years. Currently, he is studying mixtures of NiCrAlY and $Y_2O_3 \cdot MgO$ stabilized ZrO_2 (Kitahara, 1983). Layers of 0.1 mm are built up by varying the ceramic-to-metal ratio in either layers or continuously. The single layer coating lasts for 400 thermal cycles from 1088°C to 316°C, while the multilayer coating lasts for 600 cycles and the continuously changed coating can withstand 1000 cycles. Currently, SiC, TiC, and Si_3N_4 coatings are being tested. The effect of hot isostatic pressing on coating effectiveness and performance is also part of a cooperative program with the Kobe Steel Corporation.

In another study at NRIM, iron-aluminum joints have been produced using an iron oxide insert. After bonding at 1200°C at 3 kg/mm^2 pressure, a bond strength of 11 kg/mm^2 is obtained. It is believed that this process will be useful in the manufacture of turbines and pistons.

Finally, Dr. K. Yoshihara of NRIM has shown that AISI 321 stainless steel forms a TiC surface layer when annealed at 1100 K in vacuum for 30 minutes (Yoshihara, 1982). More recent studies show that this thin (50 nm) TiC coating significantly improves the bonding of Al_2O_3 or TiC to stainless steel.

Ishikawajima-Harima Heavy Industries (IHI) has been studying diffusion bonding of Si_3N_4 to steel and aluminum 6061 alloy for joints to be used in liquid fueled rocket engines. At 580°C, a maximum bond shear strength of 8 kg/mm² is typical. They have also produced $Cu-Al_2O_3$ bonds at 1000°C with 14 kg/mm² maximum shear strength with 8 kg/mm² typical. In another study of aluminum-boron composites they find 5051 and 5083 aluminum alloys do not form good bonds while 6061 alloy does form a bond. IHI plans to braze Si_3N_4 to itself using aluminum-based filler metals.

Hitachi Shipbuilding has developed bonding of Si_3N_4, SiC and sialon to Cr-Mo steel, Kovar and WC-6Co by using an aluminum-10 silicon alloy clad sheet with a pure aluminum core. The best bonds were formed when the Al-10Si alloy clad layer was molten but the pure aluminum core of the composite brazing sheet was still solid. Strengths of 43 ksi were obtained for sialon, 35 ksi for Si_3N_4 and 20 ksi for SiC, when bonded to Kovar or WC-6Co. As shown in Figure 1, the strength was strongly influenced by the differential coefficient of thermal expansion of the two materials being joined.

In another study, Hitachi obtained bond strengths up to 100 kg/mm² when bonding WC-6Co to tool steel using a Permalloy insert. This maximum strength was obtained with an optimum Permalloy thickness of 0.25 mm.

For use as a fusion reactor or MHD first wall material, Hitachi has bonded SiC•BeO ceramics which have high electrical resistivity to stainless steel, copper or aluminum substrates using a copper-carbon composite interlayer. They use the aluminum-silicon braze discussed previously. Unfortunately this limits the effective use temperature of the product. By varying the copper-to-carbon ratio in the interlayer they can vary the coefficient of thermal expansion between 6 and 10×10^{-6} per degree centigrade. Several of these joints have been tested in coal-fired MHD channels with reportedly excellent ability to withstand heat (Shida, 1985).

Finally, Hitachi has developed molecular beam epitaxy systems fabricated out of aluminum which are capable of low temperature baking to obtain ultrahigh vacuum. The interior surfaces of the system have a proprietary alumina coating (presumably anodized) while the flange joints are coated with CrN (presumably by plasma deposition). Hitachi claims that this new system will considerably reduce the cycle time for ultrahigh vacuum processing equipment.

At Osaka University, Dr. A. Nishimura is bonding Si_3N_4 to tungsten using an amorphous 80Cu-Cr-Co brazing alloy. Professor F. Matsuda is studying boronizing of gold and refractory metals and Dr. I. Miyamoto is laser welding mullite and alumina. Professor A. Matsunawa is forming TiN coatings on titanium by laser surface heating in a nitrogen atmosphere. Professor Y. Arata, director of the Welding Research Institute and the only recent engineer to be awarded the Japan Science Prize, has a large program in C-M bonding. He has studied the formation of the TiO_2 interlayer in $Cu-Al_2O_3$ joints when using Cu-Ti brazing alloys (Naka, 1983-1). In similar work on Si_3N_4 and SiC, titanium silicides were found to form (Naka, 1983-2). The Si_3N_4 joints had strength of over 17 kg/mm², but the SiC joints were less then one quarter of this value. Additional studies of alumina-Kovar joints have produced strengths of 15 kg/mm² (Naka, 1983-3).

Professor A. Omori, also of Osaka University, is studying the corrosion behavior of stainless steel with plasma sprayed layers of ZrO_2, Al_2O_3, or $TiO_2-Al_2O_3$. A recent addition to his laboratory is vacuum spraying equipment with which he is studying bonding of SiC, Si_3N_4 and WC-Co on metal substrates. He has found that TiO_2 decomposes to

Ti_3O_5 and WC to W_2C during plasma spraying. In a related study, Professor Inoue is laser remelting these plasma sprayed coatings in order to reduce the porosity and improve the corrosion performance of these coatings.

Professor Enjoh of Osaka University is studying diffusion bonding of Al_2O_3 and ZrO_2 to steel and Al_2O_3 to itself. He is also brazing Al_2O_3 to steel using Cu-Ti alloys. In simple tension tests, the fracture is in the ceramic. When bonding ZrO_2 with the Cu-Ti alloy, the Ti aggressively attacks the ceramic. An attempt was made using the Cu-Zr brazing alloy, but suboxides of zirconia formed with resultant poor properties. Professor Enjoh has also made excellent Cu-Al_2O_3 joints by oxidizing the copper before diffusion bonding. Presently they are studying Fe-Cu-Al_2O_3 composites in hope of reducing the interfacial stresses. A maximum strength of 3 to 4 kg/mm^2 is obtained when using a 2-mm-thick Cu interlayer.

At Hitachi Shipbuilding, they are studying plasma spraying, brazing, adhesive bonding, and metallizing of ceramics. They are presently producing a 90-mm-diameter ceramic capped diesel piston. Next year they expect to expand this to 120 mm and in two years to 400-mm-diameter pistons. Hitachi Shipbuilding uses interlayers to reduce the stress between the ceramic and the steel. They produce their own ceramics and are actively working on the machining of ceramics and plasma spraying for furnace coatings and turbine blades. Composite coatings of continuously graded compositions which are up to several millimeters in thickness are also being developed.

Kawasaki Heavy Industries is weaving SiC/C fibers with aluminum 6061 foil to produce fiber reinforced metal cylinders. These are diffusion bonded at 575°C at 200 kg/mm^2 pressure. They expect to apply this product in production in the near future. In addition, studies with a new vacuum plasma spraying unit have begun.

Mitsubishi Heavy Industries (MHI) has the world's largest diffusion bonding unit capable of 10,000 tons and parts of 2.5 m x 3.5 m size. They are studying diffusion bonding of Al_2O_3 and Si_3N_4 to metals in the laboratory. Brazing and adhesive bonding studies are also in progress. MHI has extensive surface coating equipment and is studying ion plating of TiN, BN, Si_3N_4, TiC, SiC, Al_2O_3 and TiO_2. Mitsubishi has made a very large investment in these surface modification laboratory facilities.

At the Tokyo Institute of Technology, Professor I. Iseki has studied bonding of SiC for many years. In one study, germanium was used as a braze alloy, (Iseki, 1981) and bending strengths in excess of 20 kg/mm^2 were obtained. In a more recent study, he has shown that Al_4C_3 forms at the interface of SiC and aluminum joints (Iseki, 1984-1) and that this compound is hygroscopic which causes long-term degradation of the joint (Iseki, 1984-2). Other studies include joining of SiC by reaction sintering (Iseki, 1983-1, 1983-2) and brazing of SiC using Ag-Cu-Ti filler metals (Iseki, 1985). Reaction sintering can produce joint strengths of 40 kg/mm^2 while brazing produces joints of only 5 kg/mm^2.

In other laboratories, the Mechanical Engineering Laboratory at Tsukuba has a special project (four to five engineers) studying C-M bonding, but no details are available. The Ship Research Institute has studied plasma spraying of Al_2O_3 for diesel engines and Toshiba is studying metallizing of ceramics. Professor Kiuchi of the University of Tokyo has made cermet pipes by blending iron, iron oxide, and alumina powders and hot rolling the mixture on the surface of steel plates. The plate is later rolled intc a pipe with the cermet on the interior surface. Indeed, nearly every month some laboratory reports a new ceramic-metal bonding technology in the popular press in Japan.

CONCLUSIONS

Much of the increase in ceramic-metal bonding research in Japan can be attributed to the Japanese group structure. If someone else is studying something, that is justification for others to study it. Most of the research cited in this article does not have a specific goal or application; it is merely an attempt by metallurgists in Japan to join the ceramic fever. Certainly one result will be a large increase in technical papers in this area within the next few years, but it also portends a decrease in the metals research papers over the same period. The traditional Japanese metals laboratories are becoming materials laboratories. This same trend is obvious in the United States but not to the extent that it is visible in Japan.

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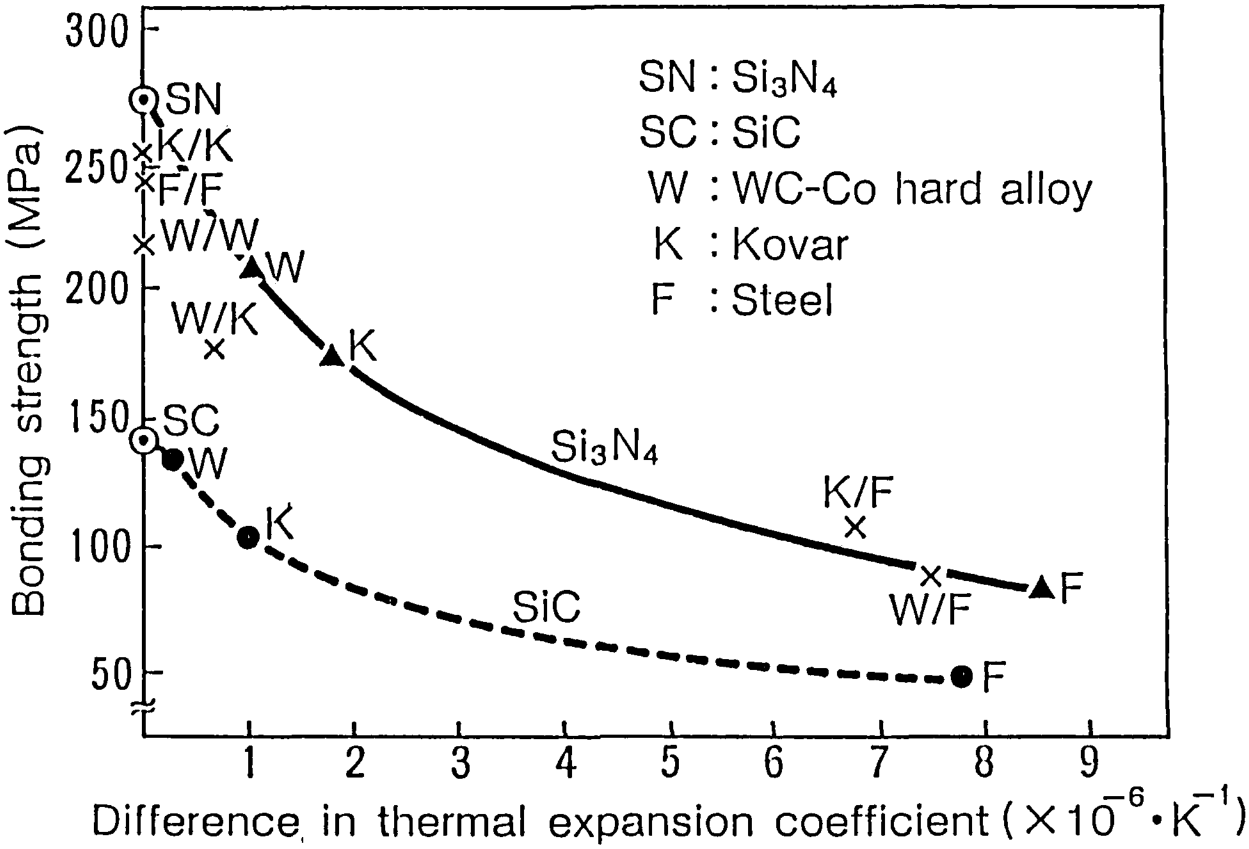


Figure 1. Bonding strengths of specimens bonded with Aℓ-Si clad metal plotted as a function of the difference in the thermal expansion coefficients (temperature: 883 K, pressure: 9.8 MPa, time: 1.8 ks interlayer thickness: 0.6 mm).

TECHNOLOGY TRANSFER AND COOPERATIVE RESEARCH IN JAPAN

Thomas W. Eagar

INTRODUCTION

There is much being written about Japanese businesses and their current success; a number of reasons have been proposed to explain this phenomenon. One of the most admired aspects in manufacturing is the Japanese ability to assimilate and apply new technology from around the world. In addition, Westerners are often impressed with Japanese preparation and knowledge concerning seemingly minor details. One American engineer tells the story of a meeting he had with a Japanese company in Tokyo one afternoon. He asked a rather specific question but received a rather general answer. The next morning, feeling unsatisfied with the response, he phoned another member of the company who was stationed at an office 600 miles away and asked the same question. His friend answered by saying that he thought that the question had been answered by his colleagues in Tokyo the previous afternoon! The Japanese company certainly had excellent communications both about what was said and about what was allowed to be said to this engineer.

Another claim which is often heard is that Japan is a unified economy tied together in some sinister way labeled "Japan, Inc." To those westerners who have spent much time in Japan yet another common characteristic of the Japanese is their apparently endless series of meetings. In this paper, I will attempt to explain some of the specific ways in which the Japanese achieve such rapid assimilation of new technology, and such excellent communications, why they hold so many meetings, and whether they are unified in their research. This is presented primarily through a description of the organization and the administration of two Japanese professional societies with which I am familiar: *viz.* the Japan Welding Society (JWS) and the Japan Welding Engineering Society (JWES); however, the general organizational format is very similar to most other Japanese engineering societies. It will be seen that these societies take a much more active role than most of their counterparts in the United States. It is believed that this active role of the professional societies is the glue which holds Japanese universities, national laboratories, and industries together and contributes not only to excellent communication of new technology but also to considerable cooperative research.

Before starting a discussion of the JWS and the JWES it may be useful to describe a few facts concerning the role of engineering and, specifically, the welding profession in Japan. In the United States, the most respected profession is a physician followed in second or third place by a scientist. The engineering profession generally ranks in the lower of the top ten professions. In Japan, the situation is reversed. Engineering is the most highly respected profession with science ranking within the top ten, but considerably lower than engineering. This difference between the United States and Japan is easily seen in the number of science and engineering graduates (Table I). There are roughly seven times as many scientists educated in the United States as in Japan, but equal numbers of engineers. On a per capita basis this means that Japan has twice as many engineers as the United States. As a result of this dominance of engineering professionals in Japan, the more practical or applied disciplines receive much more attention (and financial support) than in the United States. This is especially true for welding, which in the U.S. is considered to be on the low end of the technical scale. In Japan, welding is a much more respectable profession because the Japanese recognize that it permeates all types of

manufacturing even if it is not very scientific; welding has tremendous practical importance. This importance is illustrated by the inclusion of welding as one of the 59 national committees of the Science Council of Japan (JSC). The JSC is the statutory advisor to the Japanese government on science and the National Committee of Welding ranks equally in the JSC with National Committees of Physics, of Mathematics, of Chemistry and of Space Research. Whether one agrees with such a ranking or not, this example demonstrates the importance of the practical engineering disciplines as perceived by the Japanese.

THE JWS--A PROFESSIONAL SOCIETY FOR INDIVIDUALS

As a professional society dedicated to individual members, the Japan Welding Society is similar to an engineering professional society in the United States. It holds two annual meetings, issues publications, holds training courses and the like. There are also nine technical research committees (listed in Table II); however, what is unusual is the activity of these technical committees. Each committee meets for one or two days, four to six times each year with 50 to 100 people in attendance. With only 25% of the 4000 JWS members as active committee participants, this represents five man days of technical committee work each year per active committee member. While this alone might not seem excessive, one has to combine this with the six days of semiannual technical meetings and the activities of the JWES which will be described subsequently.

These technical research committee meetings are not short administrative groups held in conjunction with other professional society business as is often done in the United States; they are full day stand-alone meetings. As an example, in November 1984 a day-long-meeting was held by the Welding Processes Committee to discuss narrow gap welding. In the morning, five persons from industry discussed the status and future potential of this process in the pressure vessel, heavy machinery, construction, shipbuilding, and hydroelectric industries. This was followed in the afternoon with five hours of discussion concerning narrow gap welding among experts from industry, national laboratories, and universities. Such an extensive discussion on such a limited topic must have provided each of the experts with a comprehensive knowledge of the state-of-the-art of narrow gap welding in Japan, its major problems, and its future industrial potential. In essence, this was a specialized seminar, given by experts for other experts in the same field. Although very labor intensive, such a meeting is very effective in transferring technology among laboratories, and industry.

In the same month the Arc Physics Committee met to review some of the technical papers which were presented at the International Institute of Welding meeting which was held in Boston the previous July. In this way, persons not present at this international conference could be instructed in detail by their colleagues who had attended. In addition, a draft of one of the Japanese publications which will be submitted to this same international conference in 1985 was presented for review and comment. An updated review was handed out at the next meeting which was held in February. At this second meeting, five or six current research papers were presented by both universities and industry.

Although these committee meetings are officially public, the information which is shared is not readily available to nonmembers of the committee. Several chairmen explain that this public yet private issue is not a problem at present as the reports are usually in Japanese, and only committee members have copies except for a copy which is kept in the files of the JWS. When asked if the JWS files were open, it was explained that any specific

request would probably be honored but a non-Japanese person could not review the files at will. If they allowed such open access, the companies which contribute information would not be so cooperative in the future.

As another example of these open, yet closed, meetings, this author was invited by a Japanese colleague to attend another society's technical meeting. This was the Iron and Steel Institute of Japan meeting in Hiroshima in October 1984. The meeting was in Japanese, but there was a special two-day seminar of particular interest on accelerated cooling of steel plates, a new technology in which Japan clearly leads the world. Upon arriving with an interpreter, we were told that foreigners could not attend the seminar. After explaining that we were invited by a Japanese friend, apologies were made and we were permitted to enter. The surprising aspect of the seminar was that most papers dealt with the design and construction details of the processing equipment and how to avoid technical pitfalls. After the meeting, I commented that this was certainly unusual by U.S. seminar standards and my Japanese colleague responded that this is the Japanese way of "normalizing" their knowledge among the entire industry. It is not a practice that is illegal in Japan and it certainly is an effective means of intraindustry technology transfer.

Each technical research committee defines the scope of its interests. For example, the Strength of Welded Structures Committee lists the following four points of interest:

- weld cracking and residual stresses,
- fracture-safe design,
- time dependent fracture, e.g., fatigue, creep and stress corrosion cracking, and
- fabrication problems--sharing of experiences.

The chairman has four subchairmen, each of whom is a university professor, who are responsible for extracting one or two papers in each area, usually from industry, for presentation at the committee meetings. In this way, several dozen papers on weld strength are discussed in detail each year.

Another example of technical committee organization and activities comes from the Committee on Solid Phase Welding and Brazing. The JWS recognized in 1983 that more use will be made of dissimilar materials in the future and the conventional fusion welding processes are not appropriate. As a result, they formed this newest committee which held its first meeting in 1984. Starting a committee requires a strong and influential chairman. He must invite companies, universities, and national laboratories to participate. Each company pays a small annual fee ($100 to $200) to support the administrative expenses of the committee. After one year, the Solid Phase Welding and Brazing Committee now has 45 industrial members and about a dozen more from universities and national laboratories. After defining their scope, which in this case includes both metal-to-metal and metal-to-ceramic bonding, they divided up responsibilities for a worldwide literature survey of the state-of-the-art. At the next meeting, different laboratories agreed, at their own expense, to repeat some of the better studies which were found. This allows the Japanese laboratories to build up their expertise to world-class standards. In future meetings, the results of these studies will be presented and new research will be suggested. Each company can volunteer to perform some part of the study and share the results with other committee members. By such cooperative research, the Japanese can quickly develop world-class capabilities in this new area and can pool their resources to advance the state-of-the-art. While some of the early reviews of the current state-of-the-art may be published in English at the International Institute of Welding, most of the new research results will remain in Japanese with distribution limited to committee members.

Although professional societies for individuals in the United States have active technical committees, their activities cannot usually compare with the effort and the scope of the technical research committees of the JWS. Most professional society technical committees in the United States deal with topics such as public meetings, continuing education, or development of new standards. In Japan, the technical research committees function much more toward a "normalization" of research knowledge between universities, national laboratories, and industry. This is certainly one method by which the Japanese achieve rapid technology transfer from the laboratory to the production facility on an industry-wide basis. Although Japanese industry usually competes fiercely in sales and marketing of products, there is much truth to the idea that research studies are unified and coordinated and the results of this research are widely shared within Japan. In former times of rapid market growth, this sharing was very open but in the more competitive market of today's economy sharing is becoming more limited. Even so, this sharing of research knowledge is still much greater in Japan than in the United States.

THE JWES--A PROFESSIONAL SOCIETY FOR CORPORATIONS

Although the JWS is a professional society made up of individuals, the Japan Welding Engineering Society consists primarily of 160 corporate members and 300 invited personal members. The corporate membership dues are $1000 to $3500 per year and there is no fee for personal members. Although the JWES coordinates its work closely with the JWS (their headquarters are located in the same building), the JWES is primarily organized along industrial lines and their primary duties include cooperative research, qualification of engineers and welders, and the development of industrial standards.

Table III lists the technical divisions and research committees of the JWES. Each technical division has a division chairman, usually selected from an industrial company, but many also have a technical chairman, who is a university professor. The technical chairman of both the divisions and the research committees have several long-range projects. For example, The Welding Data System Research committee is trying to establish a welding data base which will be computerized. Approximately 20 companies and several universities are contributing information which can be used by everyone. It has been said that such cooperation was very generous a decade ago when the Japanese shipbuilding and steel industries were very busy, but in today's recession, it is more difficult to convince companies to share all of their knowledge. The Japanese claim that it is much more competitive now and it is only through the leadership of influential committee technical chairmen that companies can be encouraged to participate. As noted above, most of the committee technical chairmen are senior professors from the universities. Their old ties with former students make it possible to extract information which a company might otherwise avoid discussing in public.

Another example of cooperative industrial research sponsored through these technical committees, is research on a project entitled, Metal Working by High Power Lasers. In March 1980, a technical committee of the JWES was formed to evaluate high power lasers as metal working tools. The project is led by Professor K. Masubuchi of Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, who uses the 15 kW CO_2 laser at AVCO Everett (now Combustion Engineering) and Professor I. Masumoto of Nagoya UNiversity who has a 2 kW CO_2 laser. The experimental program, listed in Table IV, was financed by the 15 member companies. Each company can propose a specific portion of the research provided they are willing to provide the research funds. The advantage of this system is that not only can each company have its own specific research needs addressed, but can share in the overall results of the entire study. This is very effective cooperative research.

Of the JWES divisions, each carries out an average of three cooperative research projects per year. In most cases, companies do not directly finance the study through JWES as with the high power laser study at AVCO, but rather, they agree on which companies will perform which research and they share their research results. Any member company can request a cooperative research program by suggesting a topic in one of the division's committee meetings.

In addition to these industrially-sponsored cooperative welding research projects, the JWES often acts as a contractor for the Japanese government in administering research programs. There are currently 18 government-sponsored projects. Those sponsored by the Power Reactor and Nuclear Fuel Development Corporation (PRC), the Japan Atomic Energy Research Institute (JAERI), and the Japan Defense Agency are listed in Table V. The Ministry of International Trade and Industry (MITI) also provides monies for development of industrial standards, although the amount of money provided is very small.

When a government research contract is received by the JWES, a strong chairman is assigned who can encourage companies to participate. This is necessary because industry will receive only 10 to 30% of the total research costs while participating national laboratories and universities will receive 50 to 80% of the costs if they agree to participate. In any case, the government can have a large cooperative research program, administered by an eminently qualified expert in the field using highly-leveraged research funds.

It should be mentioned that although companies feel very pressured to participate in such projects when invited by influential chairmen, industrial participation is not guaranteed. When MITI began one of its nine large-scale industrial projects on a flexible manufacturing system complex provided with a laser, Hitachi, Toshiba, and Mitsubishi Electric were invited to participate in designing a high power CO_2 laser. Even though this was a $60 million eight-year project, Hitachi felt that they were well ahead of their competitors in laser development and they chose not to participate even under extreme pressure. Hitachi felt that they had more to lose than to gain. Today, at the end of the project, Hitachi, Toshiba and Mitsubishi Electric each have comparable CO_2 laser technology. Toshiba and Mitsubishi Electric shared their development costs with the government and shared the results with each other. Hitachi paid all of its costs itself and did not share directly in the results of Toshiba and Mitsubishi Electric.

It should be noted that for a project of this magnitude, a new professional society was formed entitled, "Engineering Research Association of Flexible Manufacturing System Complex with Laser." This association includes 20 companies and some 200 engineers from industry and 40 from national laboratories. It is clear that this society is a private administrative agency of MITI, based on the fact that questions referred to the Association two months after the project completion were referred back to MITI for response.

SUMMARY

If one asks how the Japanese achieve such effective technology transfer between laboratory and production, certainly one answer is that they hold many meetings on an industry-wide basis. There is not just technology transfer within a company, in Japan, but between companies and between companies and universities through the many meetings of the individual professional societies. The topics discussed at many of these meetings include much more technical content and detail than is common in the United States. In addition, all research laboratories become familiar with the efforts at other laboratories

resulting in rapid dissemination of new results and less duplication of effort. The meetings also permit the Japanese to communicate knowledge of works outside of Japan very effectively. The Japanese are often frustrated by multiple groups of Americans coming to learn what has already been explained to previous visitors. There is not a system in the United States which disseminates information on international research activities as effectively as the Japanese system.

There are a number of reasons why the Japanese meeting system works. One is the strong leadership of the university professors who serve as committee chairmen. There are strong ties between these professors and their former students that do not exist in the United States. Japanese industry does not have any higher regard for the research done at Japanese universities than American industry has for research at American universities, but there is a much greater respect for old acquaintances in Japanese society as compared with American society. Another factor is the community spirit of the Japanese rather than the individualistic spirit of Americans that makes the Japanese more willing to share their successful ideas with one another rather than keeping them to themselves for private advantage. Still another factor is the greater patience of the Japanese. Few senior American scientists would tolerate spending 10 to 20% of their time in outside professional meetings in addition to the internal meetings within their organizations. Finally, a very important factor contributing to successful technical meetings in Japan is the Shinkansen, the "Bullet" Train. In many ways the small size of Japan is a curse, but insofar as holding meetings, it is a blessing. With the Shinkansen, most people can attend a one-day meeting at relatively small expense and only consume one day of their time including travel.

These differences suggest that the Japanese method of technology transfer cannot be transferred directly to the United States with equal effectiveness. Scientists in the U.S. should consider which aspects of the Japanese system of technology transfer can be used and should then try to implement such changes. One thing is certain, the impression that the Japanese have more effective technology transfer is true, and there is probably much that the United States can learn from the Japanese in this regard.

The Japanese methods of coordinating and cooperating in research could probably be used effectively in the United States if they were not illegal under U.S. statutes. There is much duplication of research effort in the United States. One thing which we can learn from Japan is that cooperation in research does not mean a lack of competition in the marketplace. Japanese businesses compete actively, while also cooperating in research. In contrast, American industry is hampered by laws and regulations which were made 75 years ago in a very different world economy. While the concept of a "Japan, Inc." in the world marketplace is not very accurate, there is a form of "Japan, Inc." in the research community. As one Japanese leader stated, "In order to avoid the useless duplication of research work and to push forward the development and application of research efficiently [to] needs in industry, it is preferable to establish a study system for joint research [by] industrial and academic circles."[1] Japanese research money is spent more efficiently because of this strong cooperative research effort.

[1] "Welding Research in the Far Eastern Countries," in *Proceedings for International Congress on Welding Research,* T. Kobayashi. Welding Research Council, New York, 1984.

TABLE I

SCIENCE AND ENGINEERING GRADUATES
IN THE UNITED STATES AND IN JAPAN

	United States	Japan	Ratio
Physical Sciences			
Bachelor	83,859	11,803	7.1
Master's	15,318	1,710	9.0
Doctoral	7,374	822	9.0
Engineering			
Bachelor	71,094	75,188	0.9
Master's	18,550	6,975	2.7
Doctoral	2,742	1,186	2.3

TABLE II

NINE STANDING TECHNICAL RESEARCH COMMITTEES
IN THE JAPAN WELDING SOCIETY

Technical Committee on Strength of Welded Structures
Chaired by Professor K. Satoh (Osaka University)

Technical Committee on Welding Arc Physics
Chaired by Professor H. Maruo (Osaka University)

Technical Committee on Welding Processes
Chaired by Professor I. Masumoto (Nagoya University)

Technical Committee on Welding Metallurgy
Chaired by Professor F. Matsuda (Osaka University)

Technical Committee on Fatigue Strength of Welded Joints
Chaired by Professor K. Iida (University of Tokyo)

Technical Committee on Electron Beam Welding
Chaired by Y. Arata (Osaka University)

Technical Committee on Resistance Welding
Chaired by Professor S. Nakada (Osaka University)

Technical Committee on Microjoining
Chaired by Professor S. Nakada (Osaka University)

Technical Committee on Solid Phase Welding and Brazing
Chaired by Dr. H. Nakamura (National Research Institute for Metals)

TABLE III

JAPAN WELDING ENGINEERING SOCIETY
TECHNICAL DIVISIONS AND RESEARCH COMMITTEES

Technical Division

- Welding Filler Metal
- Electric Welding Machine
- Gas Cutting
- Shipbuilding and Marine Structure
- Aircraft
- Machinery
- Rolling Stock
- Automotive
- Civil Engineering
- Patent
- Iron and Steel
- Precious Metal Brazing

Research Committees

- Special Materials Welding
- Chemical Plant Welding
- Nuclear Engineering
- Plastic Design
- Robots Promotion
- Welding Data System Research Committee

Committees for Contract Research

(Currently about 18 in total)

TABLE IV

SUMMARY OF RESEARCH PROGRAM CARRIED OUT BY HPL COMMITTEE OF JWES [a]

Theme	Mark of Experiment		Titles of Experiments	Members	Time* Schedule	Remarks
on beam characteristics	A		The relation between beam power and beam profile	K.H.I.	Step 1	AVCO
	B	B-1	On TEM mode	O.T.C.	Step 1	AVCO
		B-2	Beam profile	O.T.C.	Step 1	
	C		Influence of slope-up and slope-down to weld penetration	Toshiba	Step 1	AVCO
	D		Slope bead on plate test	K.H.I.	Step 1	AVCO
on welding	E	E-1 E-2 E-3	The relation between welding conditions and penetration and/or weld defects	M.H.I. I.H.I. O.T.C.	Step 2	AVCO
	F		Bead on plate test of aluminum alloy	Nissan	Step 2	AVCO
	G		Mechanical properties of HPL welded joints	S.H.I. Kobe St. Hitachi	Step 3	AVCO
	H	H-1	Fillet welding of aluminum alloy	Mitsui	Step 3	AVCO
		H-2	Fillet welding of steel plate	N.K.K.		
on heat treatment	I		Fundamental study on beam pattern	Toshiba	Step 1	AVCO
	J-1		Hardenability of materials	Nippon St. S.H.I. Hitachi S. M.H.I.	Step 2	AVCO
on cutting	K-1		Thick plate cutting	O.T.C.	Step 1	AVCO
	K-2		High speed cutting of thin steel	Hitachi	Step 2	UTRC
	K-3		Cutting of heated steel plate	Kawasaki S.	Step 3	AVCO
on practical applications	N		Irradiation test for sintered silicon compound	Nissan	Step 3	Nagoya Uni.
	O		Study of precise bending by laser line heating	N.K.K.	Step 2	AVCO
	P		Lining welding of stainless steel	Mitsui	Step 3	AVCO
	Q		Joining of ceramics to metals	Daido	Step 3	Nagoya Uni.
	R		Surface alloying	Hitachi	Step 3	AVCO
	S		High speed welding of thin stainless steel	Hitachi	Step 3	AVCO

	Planned period	Actual period
*Step 1:	from Oct. 1980 to April, 1981 !	from Nov. 1980 to June 1981
Step 2:	from March 1981 to Aug., 1981	from Oct. 1981 to Sept. 1982
Step 3:	from July 1981 to Jan., 1982	from Jan. 1982 to Dec. 1982

[a] Reference for Table IV taken from *Technical Report on Research on Metal Working by High Power Laser* by Massachusetts Institute of Technology to the High Power Laser Committee of the Japan Welding Engineering Society, September 26, 1983.

TABLE V

JWES-ADMINISTERED GOVERNMENT RESEARCH

- Sponsored by the Power Reactor and Nuclear Fuel Development Corporation

  Acoustic Emission Signal Analysis for the Purpose of Structural Integrity of Piping Components for Fast Breeder Reactors (FBR)

  Establishment of Welding Procedures for FBR Structural Components

  Creep-Fatigue Crack Propagation Behavior of Structural Materials for Liquid Metal FBR

  Nondestructive techniques for FBR Structural Welds

  Structural Design of FBR

- Sponsored by the Japan Atomic Energy Research Institute

  Fatigue Strength of Light Water Reactor (LWR) Components

  Fracture Mechanics Evaluation of LWR Primary System

- Sponsored by the Japan Defense Agency

  Welding Code for Ni-Cr-Mo-Nb Ship Steel

  NDE of Steel Weldments--Development of Standards

  High Deposition Rate SMAW for Submarine Steels

  Standards for Fabrication of Submarine Hulls

IMPRESSIONS ON PRECISION ENGINEERING IN JAPAN

Ray McClure

INTRODUCTION

Everybody knows of Japanese progress and dominance in various technological domains such as cameras, cars, and consumer electronics. Less obvious, but also very important, are the Japanese achievements in "precision engineering."

In America, precision engineering (PE) has multiple origins and an uneven status.

Three years ago, the Office of Naval Research started a program to encourage the development of precision engineering education and research in U.S. universities. ONR now has four universities under contract. Progress to date has been encouraging enough to suggest that further development of an academic base for precision engineering in the U.S. to be worthwhile and feasible. However, at the present time, conditions in the U.S. are such that, although some progress has been made in recent years, the title "precision engineering" (PE) often has been poorly received, has been confused with other "buzzwords" such as "manufacturing engineering," or has been met with suspicion that it is just another ploy on the part of academicians to obtain funds from the U.S. government. In Europe, there has been some acceptance of the concept of precision engineering, as evidenced by the existence of the Cranfield University Unit for Precison Engineering (CUPE) in Great Britain, and the existence of a private publication entitled *Precision Engineering*, which sponsors annual international conferences on the subject.

In Japan, there apparently is no such confusion or lack of acceptance of the concept of precision engineering as a distinct profession. Publications bearing the title "precision engineering" and the existence of departments of precision engineering at many Japanese universities indicate that precision engineering is an integral part of the Japanese academic and industrial scene.

In 1984, the author was commissioned by ONR to conduct a four-month study of precision engineering in Japan. The main objective was to derive a fairly broad state-of-the-art assessment of precision engineering in Japan. Specific technical areas which were targeted for U.S.-Japan comparison were precision machining and optical polishing and grinding. Machine tool design, control system methodologies, and basic research into material removal processes were also within the purview of the study. In addition to the strictly technical explorations, the Japanese methods of planning and executing R&D and commercial exploitation of precision engineering were planned. Though it was often possible to estimate whether Japan was "ahead," "behind," or "about even," with America in a given area, all such judgments have the potential for bias, ignorance, and contamination. Sometimes, the author believes, it is simply best to assume that the Japanese are good, worthy colleagues and competitors.

The basic approach of this study was a direct technologist-to-technologist contact. During the four-month period, personal visits were made to nearly all centers of precision engineering activity in Japanese universities, government laboratories, and industrial firms. Usually, a visit was arranged for the purpose of technical exchange on a specific topic rather than for a general visit. Overemphasis on the "score" or relative standing of the two countries may hinder awareness and communication.

During the four months, almost 50 technical exchanges were conducted. The sites embraced 13 universities, 19 commercial companies, and eight government laboratories. A complete list of visit sites is appended to this article.

THE JAPAN SOCIETY OF PRECISION ENGINEERING (JSPE)

At the very start of the tour, early October 1984, the JSPE held its fall meeting in Niigata. With some 800 in attendance, the meeting facilitated introduction both to Japanese technical papers and to the main R&D personalities. Though all the papers were presented in Japanese, the author discovered that his familiarity with the topics, and the fact that many of the visual aids were captioned English permitted the author to obtain some technical information.

In its publications, the JSPE describes itself as follows:

> The Japan Society of Precision Engineering (JSPE), founded in 1933, is an institute authorized by the Ministry of Education and presently has a combined membership of approximately 6,000 individuals and corporations.
>
> JSPE was started for the purpose of discussing common problems and future developments by a group of mechanical engineers and research workers who were especially concerned with "preciseness." JSPE has since developed to encompass all engineering fields that require highly advanced technology and now plays a leading role in the research and development of production systems, instrumentation, system control, CAD/CAM, as well as precise elements.
>
> The society is also contributing to the education of engineers by acting as the center of various research and development organizations which are directed toward new technology including LSI, medical equipment, new instrumentation concepts, new machining processes, unmanned manufacturing systems, etc.
>
> The society is devoted to rapid publication of papers and the introduction of the latest technology through the monthly publication of the transactions *Seimitsu-Kikai* in Japanese and the English quarterly *Bulletin JSPE*, as well as convening semiannual spring and autumn conferences, and various symposia and lectures. JSPE is organized into seven branches which act to exchange information and the state of research and technology in the local districts.

Incidentally, the JSPE *Bulletin JSPE* contains English abstracts of the papers published, during the previous quarter, in its Japanese-only *Transactions*.

Three hundred and thirty one papers were presented at the Niigata meeting, and each was limited to two or three pages, including figures. The oral presentations were carefully timed to ten minutes; as far as I could tell, most papers were carefully reviewed in advance and nearly every presenter received questions. I was told that most papers represented progress reports on incomplete work, and that the discussions contained constructive suggestions as well as criticism. Many papers were presented by competing commercial companies. Apparently then, much basic research in PE was quite openly disclosed and discussed.

ULTRAPRECISION MACHINING IN JAPAN

Ultraprecision machining probably is receiving more public attention and scrutiny in Japan than in any other country. At least two special committees, one within the JSPE and the other within the Japan Society of Mechanical Engineers, are actively surveying and reporting on the technology.

In a major review article, first published in Japan and later in the annals of the CIRP, Dr. Norio Taniguchi has analyzed the past (from 1900), present, and future (to 2000) of accuracy and precision in material fabrication processes. Figure 1 summarizes Dr. Taniguchi's analysis.*

A great virtue of Taguchi's work is that it provides many parameter summaries which afford the assessment of past progress, and also encourages projection into the future. It can be argued that precision is really relative and that precision should be expressed in parts per million, rather than in absolute dimensions of micrometers and angstrom units. More complex features such as shape and profile accuracy can also be included in such an analysis.

Dr. Taniguchi examines the current status, and possibilities for the immediate future in several processes, such as mechanical material removal, machining and abrasive processes, particle beam erosion, and atomic deposition. He also takes a commercial-application stance: given that high energy lasers have such potentiality for the production of ever more perfect and precise elements, how can the need for ultraprecise components be satisfied and what are the real limits. From his examination, he has established expectations for each process and, without being exhaustive or too specific, he delineates problem areas and potential solutions. As one example, he notes that a problem that exists right now is to develop means to measure or inspect fabricated parts to a level which he fixes at ten nm.

CHIP-REMOVAL PROCESSES

Japan has very advanced commercial application of advanced precision machining, in the form of lathes and flycutting (single-point milling) machines using diamond cutting tools. At least seven Japanese companies are making and/or selling such machines; among the manufacturing applications are computer memory discs, memory drums, gravure rolls, polygonal rotating scanning mirrors for bar-code readers, and more mundane applications such as the machining of mirrors for ladies cosmetic cases. Components for two-axis contouring machines, such as aerostatic spindles, are being sold for use in making contact lenses and other precision turning operations. However, only Toyoda Machine Works has a two-axis CNC contouring machine on the market as a catalog item, and reportedly none of these have yet been sold. Other companies report that they have built two-axis (possibly three-axis) contouring machines; these have presumably disappeared into corporate laboratories, and are being studied for future markets.

Toshiba Tungalloy has built a contouring machine for the purpose of making copper mirrors; some of the mirrors are used in the high-energy lasers employed at the Flexible Manufacturing (System) Complex Provided with Laser (FMC) project at Tsukuba Science City. This first machine is a two-rotational axis machine. A new machine is being built as an x-z machine with linear slideways. Incidentally, there are differing company preferences

*Taniguchi, Norio, "Current Status in and Future Trends of Ultraprecision Machining and Ultrafine Materials Processing." *CIRP Annals*, *32* (2) 573, (1983).

preferences in component design. Granite bases seem to predominate, but some machines are built on steel weldments. Some companies prefer all aerostatic bearings, while others prefer all hydrostatic.

Toshiba (Shibaura) is selling its own design aerostatic spindle, with built-in motor and magnetic coupling as a separate product. The American-made Professional Instruments (Minneapolis) "Blockhead" spindle is also very popular in Japan.

In those areas where the Japanese have already become experienced with commercialized diamond turning, they seem already to have such an advantage that it is unlikely that American builders will even try to compete. On seeing the display of Japanese machines at the recent Japan Machine Tool Show in Tokyo, one American company representative was heard to say that his company had been considering competing, but that he felt that it was too late.

It is a different matter with respect to contouring diamond turning machines. There are at least two American-built machines in Japan, with a projection of three more to be purchased. The author knows of one that is due to be delivered in the fall of this year. In addition, at least one machine is being built by a Japanese company (not a machine tool builder) for its own use. At present, the machine tool builders seem to have doubts about the market for such machines. One of the questions which the writer often was asked about concerned the market potential for aspheric optics for high-energy lasers. Size is also a question in terms of market potential. There is no perceived Japanese market for the over-meter sized machines now being built and sold in the U.S.

The Mechanical Engineering Laboratory at Tsukuba Science City is currently designing and constructing an 0.5 m vertical spindle two-axis diamond turning machine and has plans for a following machine of 2-m capacity. This machine embodies a novel feature in the form of hydrostatic lead screws for the slide drives. In the same lab, a fast tool servo device has been built using a piezoelectric driver and LVDT feedback.

There are experiments with aerostatic lead screws, (Professor Inasaki, Keio University), and they have been utilized in at least one production machine design. And one specially-built Japanese machine is using traction or "capstan" drive, as the most advanced U.S. machines do.

Among the areas in which this author feels that the Japanese are definitely ahead are those of the tool materials and, possibly, tool preparation and effects of cutting on workpiece material. Professor Ikawa of Osaka University has accumulated a wealth of experimental data on the properties of diamond tools, both natural and synthetic, and has devised many property-testing procedures; among these are microhardness and defect detection using infrared techniques, electron spin resonance measurements, x-ray diffraction, and others. In addition, he has studied the possible mechanisms for tool breakdown, including the high-temperature solubility of diamond/carbon in various materials. His theoretical work has included studies of models to predict minimum chip thickness and material damage. Similar work has been done elsewhere in Japan; one illustration particularly by Professor Moriwake at Kobe University, who has acquired a single-axis machine built by Toshiba. It is now being used in a flycutting mode for tool studies.

Dr. Uda at Kanazawa University is conducting cutting studies; his setup employing a scanning electron microscope on amorphous materials is similar to that of Dr. Jay Black at

Ohio State University on single and polycrystalline materials. Professor Uda at Utsonomiya University is studying the cutting of ultrapure and solid solution materials using a flycutting machine.

Some intriguing work on potential cutting tool materials is underway at the National Institute for Research on Inorganic Materials (NIRIM) at Tsukuba. Researchers there have produced an improved, nearly single crystal cubic boron nitride, called "translucent CBN or T-CBN." Lawrence Livermore National Laboratory obtained a specimen of this tool material from a commercial Japanese source, and found it to be much superior to any yet tested for precision machining of ferrous materials.

NIRIM has just completed installation of a 30,000-ton belt press with a sample capacity of one liter. From discussions with a Japanese company, it appeared that the company sees the potential in the development of alternative materials to diamond, especially in single-crystal form.

NIRIM is also doing remarkable work on chemical vapor deposition of thick films of single crystal diamond. This research, coupled with NIRIM's high pressure physics capability, make it an important resource in the development of advanced precision machining technology. Oddly enough, NIRIM has almost no interest in the tool material application; staff members see their work as most important to VLSI substrate development.

The Taniguchi review refers to the problem of obtaining the sharpest possible edge on a diamond tool; it suggests an ion-milling process that he believes to hold promise. There was some discussion of this possibility at the JSPE Niigata meeting and, again, at Saitama University, where there is an ion source that will be used for this purpose. Alternatives to ion milling are the more traditional methods of tool polishing on which there is considerable work underway. The common problem, however, is how to measure the radius or "sharpness" of the tool edge. There has been some experimental success of measurement at 2 nm resolution, which is close to the theoretical limit of sharpness.

GRINDING AND POLISHING

As is true in other parts of the world, there is a lot of work going on in Japan on various aspects of grinding, especially toward improving the production rates of grinding processes. Creep grinding is being studied both at universities and in industry although, it is reported that this work is new. Grinding of ceramics is an especially active field right now. One example of work underway is at the University of Tokyo, where Professor Nakagawa has developed a sintered cast iron/diamond grinding wheel/tool, which he is using to grind intricate shapes. This project was suggested by Dr. Tamaoka of Osaka Diamond Industrial. Dr. Miyashita has recently completed work, supported by a private company, on improving the precision of a small centerless grinder. The grinder, in turn, was used to produce a high-quality grinding wheel quality for internal grinding of precision bores.

At the Toyohashi University of Technology, Professor Horiuchi has several active projects on grinding precision. In one project, a programmable controller is coupled with an accelerometer mounted on the headstock of a grinder. It corrects for wheel imbalance by squirting water from a nozzle into pockets milled into a plate mounted on the side of the wheel. This results in a continuously balanced grinding wheel, with consequent reductions in surface degradation due to vibration. In another project, he couples an

acoustic sensing unit, a spectrum analyzer, to obtain a means of identifying the "spark-out" process. The object is to enable a grinding process to converge as quickly as possible to "spark-out," and to prevent overshoot which may lead to "burning" or damage to the part. In still another investigation, the Horiuchi team is studying the relationship between the rotational speeds of the wheel and workpiece in cylindrical grinding to determine the conditions for minimum "lobing." This project employs his own design for a cone-and-ball live center to improve centering. There are also parameter studies into CBN grinding wheel characteristics.

At Saitama University, Professor Kasai and his students are working on fixed abrasive processes for grinding flat surfaces. A cupped face grinding wheel is used. The grinding wheel rotates at about 1500 rpm and the turntable rotates at about one-fifth of the wheel speed. Excellent results in a variety of materials are reported. With surface roughnesses of less than 0.01 μm. The surfaces appear to be very nearly specular.

However, it is in the area of loose-abrasive polishing that the Japanese are doing especially outstanding work. A three-professor team at the University of Osaka (Professor Ikawa, Professor Mori, and Professor Namba) has developed two forms of a style of polishing. Japan may be the world leader in this technique. Professor Mori calls the polishing process "Elastic Emission Machining," and in it the ultrafine abrasive particles are accelerated by the surface of a fast-moving tool. Figure 2 shows the basic components of the elastic emission machining apparatus. A ball made of polyurethane is spun at high speed on a belt-driven axle. The ball's surface does not contact the surface of the part being polished, but is located a fraction of a millimeter away from it. The part being polished and the ball are immersed in a slurry (which is usually water and the abrasive). The abrasive is an especially fine silicon dioxide made in a strictly uniform size of about 60 Å.

Professor Namba has adapted the elastic emission machining concept into a form he calls "float polishing." The name came from the fact that the part being polished is allowed to "float" as it is supported by the hydrodynamic forces created by the slurry flowing between the tool and the part. Figure 3 shows a schematic of one machine designed by Professor Namba on which he has developed his float polishing method. The tool is a rotating plate of tin which is specially grooved to produce small eddy currents or turbulence which is distributed in the space between the tool and workpiece. The surface of the tool, after it is grooved, is turned flat with a diamond cutting tool. While it is being polished, the workpiece is rotated at almost the same speed as the tool, at a speed of from 50 to 100 rpm. Professor Namba's machine is truly unique in that it has incorporated diamond turning and is, in fact, a diamond turning machine. The purpose of the machine is to produce ultraflat and ultrasmooth surfaces such as those required for substrates in very large-scale integrated circuit chip fabrication. Using this machine, Professor Namba has produced surfaces in glass and other materials that have been measured by several laboratories, to be smooth to under 2 Å/rms.

Elastic emission machining and float polishing have in common the fact that material is removed as a result of impact of the abrasive particles moving at high velocity. The tool, being made of very soft material, wears very little; the workpiece, consisting of relatively hard material, wears very rapidly. Because of the high velocities attained by these procedures, the wear rates of elastic emission machining and float polishing are competitive with those of more conventional polishing methods.

A noncontact polishing scheme similar to both elastic emission machining and float

polishing is used at the NTT Electical Communications Laboratory in Musashino. The part is supported hydrodynamically, as in float polishing, but the tool is a specially shaped synthetic rubber with the shapes of radial grooves like that shown in Figure 4, to generate optimum hydrodynamic pressure fields. In this case, the workpiece does not rotate.

Another form of noncontact polishing has been developed by Professor Kasai of Saitama University. The method is really a variation on more conventional polishing. The workpiece is supported in a holder that is made of a harder material than that of the workpiece. Because the holder wears more slowly than the workpiece, the surface of the workpiece gradually wears until it is no longer in contact with the tool surface.

A big advantage for noncontact polishing is that, because the final material removal process does not permit direct distributed contact, the material near the surface of the workpiece should be much less damaged than that of workpieces polished in more conventional ways.

Professor Mori's elastic emission machining machine has been duplicated at least once, and has been used by Dr. Hongo at the High Energy Physics Laboratory in Tsukuba Science City to produce mirrors for synchotron radiation. These mirrors have been produced in copper with a figure accuracy of 100 Å and surfaces to 5 Å/rms.

Professor Namba's float polishing machine has been replicated by the Toyoda Machine Works and is now being sold for a variety of applications in electronics fabrication, and for polishing the ferrite recording heads for video tape recorders. The ferrite recorder heads are produced in large quantities by this method; very sharp corners are required to mount heads for different tracks very close together.

METROLOGY

Ultraprecision machining developments, and their applications, are dependent on corresponding developments in the capability to measure shape, size, and surface finish. Japanese measuring techniques and devices for laboratory research are often quite advanced. Dr. Tanimura at the National Laboratory for Metrology and Professor Sato of the University of Tokyo Institute for Industrial Science are both exploring means of rapidly sensing, recording, and characterizing the topography of an area of surface, and both are employing a special form of raster-scan. Scanning electron microscopy, laser beams, and other forms of light are under investigation. Professor Saito, Dr. Kishinami, and Dr. Miyoshi at Hokkaido University are working on developments of both contact and noncontact devices to sense shape and surface finish. At Kanazawa University, Professor Kohno has produced a noncontact surface finish sensor with one nanometer resolution; this device is now available from a Japanese manufacturer. Much effort is being applied in several laboratories to develop noncontact detectors of size, surface finish, and machine geometrical accuracy; most projects aim at either in-process or nearly in-process measurement.

THE JAPANESE MACHINE TOOL INDUSTRY

There are approximately 250 machine tool builders, approximately half of which are members of the Japan Machine Tool Builder's Association. This number may be compared with approximately 700 builders in the U.S., approximately 400 of which are members of the National Machine Tool Builder's Association. Japanese companies tend to be somewhat larger in number of employees, and the largest tool companies are more likely to be part of

a large corporate conglomorate than is true in the U.S. In recent years, Japan, has apparently been able to win the "fewer workers" race (the main competitors are the U.S. and West Germany). The manpower difference can be easily seen by visiting the different factories. In Japan, the norm is one machine operator operating several electronically controlled machines, perhaps four at one time. On the other hand, I recently visited a U.S. nonmachine tool builder's factory, equipped with much the same equipment, but in the American plant the norm was one operator for each machine. Another difference is that, in Japan, it is corporate policy to use the company's products in its own production; this is done, at least partly, as an immediate means of understanding the product and wringing out the bugs before offering the product on the market. This appears to be particularly true of Japanese FMS's and other leading edge automated systems. In contrast, it appears that in the U.S. that the production department of a machine tool builder often must defend the "purchase" of its own products on a return-on-investment basis. The result is that often a U.S. machine tool builder of advanced technology machines actually has none for its own use. In addition to testing new products in production in their own factories, Japanese machine tool builders seem to prefer to first market their products in Japan for further field testing. The Japanese market is viewed by manufacturers of all kinds as the toughest and most competitive in the world. For the machine tool builder this means a tough, smart customer who provides swift, cogent feedback (in Japanese) with fewer legal entanglements than would be true, say, in the U.S. And if a product can survive and flourish in the Japanese market, it has good prospects of doing so in America and in Europe.

In Japanese machine tool companies, between 10 and 50% of the employees have some kind of engineering degree. The larger companies expend about 8% of their operating budget on research and development, with emphasis on development. A big company can be expected to have centralized laboratories for machine tools and related technologies, and it maintains good contacts with research laboratories in other parts of the corporate family. This results in rapid cross-flow of new technology.

Another East-West difference: typically, a Japanese machine tool company, even a small one, prefers to design and assemble everything it sells. For exammple, every machine tool company visited made its own electronic controls. In Japan, the engineering of total mechanical-electronic systems has become labeled "mechatronics." Thus the Okuma company refers to itself as a mechatronics company and its new logo is said to represent that fact.

"Overtime" and "job classification" are terms that are virtually unknown in Japan. When a shipment is behind schedule, the engineers, designers, office staff and others in the company will turn out to assist in the shop. The result is that a complete machining center can be and is delivered 14 weeks after receipt of the order. Every newly-hired "freshman" is required to first spend time gaining experience in the production process. The Japanese tradition of twice yearly bonuses, which may be equal to two and a-half months salary, are believed to provide incentives to work long hours and to perform any job required.

It appears that no new product idea is too dumb. The attitude in Japanese companies seems to be one of much more willingness to try out a new idea and see if the market responds, rather than to wait to see what the customer asks for.

The Japanese reluctance to assimilate ultraprecision machining technology is much less than in the U. S. The largest Japanese machine tool builders, Toyoda and Toshiba, have both assimilated diamond turning and precision grinding for the computer, laser, and electronics markets. Hitachi Seiko and other, smaller companies have done likewise.

Toyoda was able, within six months of the creation of the original design by Professor Namba of Osaka University, to deliver the first "float polishing" machine which is now a large seller for Toyoda. Toyoda has reported an annual sales volume of 70 diamond machining and precision polishing units and I was told that Hitachi Seiko ships about 50 units annually. The current market for such machines is not easily estimated, but I think a conservative estimate would be $200 million per year, and increasing.

INTERACTION OF GOVERNMENT, UNIVERSITY, AND INDUSTRY

The writer tried to discover some of the interactions between the Japanese government, academia, and industry. It is often stated, for example, that the Ministry of International Trade and Industry (MITI) is something of a shrewd conspirator or hidden power force in Japan R&D, and such agencies have received much criticism in the American press.

As far as precision engineering is concerned, at least three central themes that distinguish the Japanese interactions can be discerned; they are:

- the traditional relationship between professors and their students and between fellow students,
- the practices of the Ministry of International Trade and Industry (MITI), and
- the existence of voluntary interinstitutional committees.

The traditional relationship between a major professor and his students involves rather close personal ties; one might even say that there is some semblance to a family. Indeed, if a student marries, the professor often is expected to participate as a principal. Since weddings are among the most important social rituals in Japan, this is, indeed, indicative of a specially close relationship between professor and student. These ties seem to persist well past the college years. Students of the same professor, although they may not be contemporaries, seem to have similar familial feelings that persist. The overall result is that a complex and persistent network of personal ties originated in college, can be decisive regarding careers of Japanese technologists. Over and over again, one can observe the impact of the professor-student connection.

Besides maintaining large laboratories for specific generic research and development, MITI supports multi-institutional technical development projects. And the bulk of MITI's financial support goes to industry. For example, MITI funded the design and construction of the project called the Flexible Manufacturing Complex Supplied with Laser (FMC), which is a seven-year $65 million facility located at Tsukuba Science City. Initiated in 1977 and "completed" in 1984, this project was intended to promote the development of flexible manufacturing systems. It provided a central and well-equipped test bed for novel ideas such as the use of lasers for material preparation, welding, deburring, chip management and automatic inspection. The funds supplied by MITI were divided into two main parts. Ten percent went to the Mechanical Engineering Laboratory to pay for generic technical support; 90% percent went to the consortium of companies that actually did the work. People from other government laboratories and from academia participated as well, but do not show as funded elements (the Japanese practice is to funding manpower separately from all other cost factors). In fact, the FMS project probably involved more than $65 million. This is because private companies often do work for the Japanese government at a loss. Among the reasons: a perception that it is an honor to be invited to participate, or the belief that the experience will benefit the company because of the technology learned. Then too, university and government employees often serve as

technical leaders or directors without being budgeted themselves or without directly managing any fund expenditures.

Every government agency uses voluntary committees to provide analyses of and recommendations on key issues. For example, it was apparently on the recommendation of a committee of the Japan Society of Mechanical Engineering that MITI initiated the FMC project. Recently, the Diet provided six billion yen ($24 million) to support a committee reporting to the Prime Minister on the question of Japanese creativity. It is probably significant that the Japanese describe memberships in professional societies such as the JSME and the JSPE in terms of member organizations or companies, instead in terms of individual memberships. Under such conditions, it would appear that committee recommendations are met with built-in momentum for realization.

Perhaps the hardest evidence on the subtle but powerful interactions between academia and industry is the presence of equipment in university laboratories that is "on loan," or that can be purchased at prices much lower than cost. Here it is necessary to distinguish between private universities and national universities. As an aside, 80% of Japan's university students are in private universities which receive subsidies from the government amounting to from 10 to 20%. Private university professors can take contracts for research and development from private companies whereas national university professors are prohibited from receiving funds from private sources. Consequently, national university professors interact with companies on the basis of favors and honoraria.

PRECISION ENGINEERING EDUCATION

Sometime before World War II, an academic department at the University of Tokyo was dedicated to military ordnance such as rifles. Another at Tohuku Institute in Sendai was dedicated to the study of toothed gear design. Both these departments were redesignated as departments of precision engineering. At about the same time, the Japan Society of Precision Engineering was formed. Today there are, by various counts, at least two dozen and perhaps as many as one hundred departments, chairs, or professorships in precision engineering. There is still no completely unique profession, however.

Some of the educational confusion is engendered as a consequence of bureaucratic manipulation within the Ministry of Education. In some university catalogs one finds a Department of Mechanical Engineering I and another for Mechanical Engineering II. This occurs, apparently, because of a decision to have two professorships in Mechanical Engineering. In some places, such duplication has been avoided by creating a Department of Precision Engineering. Consequently, from catalogs, rosters, and courses it is often difficult to distinguish between mechanical engineering and precision engineering.

The Japanese use a traditional form of academic grouping consisting of full professor, two or more assistant and associate professors, a research associate, ten or more undergraduate students and five or more graduate students. Consequently, such a group usually exceeds 20 in number. Regardless of whether we choose the larger or the smaller estimated number of such groupings, the total number in Japanese universities involved in precision engineering is in the hundreds. In contrast, the corresponding number in the United States is an order of magnitude-less.

The group surrounding a particular professor works together, usually has a student room for the group, and designated laboratory space. Fourth year undergraduate students are required to perform a senior project and they probably will assist graduate students in

their experimental work. The result is continuity of work and a cross-coupling of individual projects. The typical project, either undergraduate or graduate, is highly practical. I observed an experiment in a senior project that was directed at developing a commercializable form of an unusual casting technique. There is much interest in the mechatronics combination of electronics and mechanical design and materials fabrication.

Back in the 1950s, the Japanese government set out to create 20 new schools of engineering and technology. The last of those new schools was the Toyohashi University of Technology which was completed only eight years ago. Interestingly, most of these schools are now centers of activity in precision engineering. Entirely new schools, such as Toyohashi, or new facilities at older universities (Automation Research Institute at Kyoto) resulted from this program.

In contrast, during the same period in the United States, departments of industrial engineering and mechanical engineering were closing down courses in manufacturing and process technology and substituting operations research and other theoretical courses. It is not surprising, then, that American machine tool companies that are now trying to recruit college graduates with training and, experience in manufacturing and machine tool design find the available supply of good applicants to be pitifully small. In Japan, there is a good supply of such "freshmen." I was impressed that, in many of my visits to Japanese companies, the groups I met included several young men who exhibited a high level of comprehension and skill. And, these young men usually had a working knowledge of English. At Toyohashi, undergraduates are engaged, as part of their training, in translating the *Machine Tool Task Force* report (1600 pages on the state of machine tool technology) from English to Japanese.

Another distinguishing feature of the Japanese academic scene is the existence of many recently published textbooks, for both undergraduate and graduate use, on metalworking and other aspects of precision engineering. These textbooks exist only in Japanese. The last textbook of this kind in the United States was written almost forty years ago.

CONCLUDING REMARKS

A general comparison of precision engineering in Japan and that of the United States reveals stark contrasts in style and content. The style differences are probably the artifacts of the historical differences in national priorities. In the United States, there are a few very outstanding centers of activity, capability, and achievement. These centers result mainly from the DOD support, and they were created and maintained for military programs. On the other hand, in Japan, there are many centers of PE activity with average capability and a few that are outstanding. (The best Japanese PE operations are probably not as good as the best in America.) In Japan, there is an almost total absence of military priorities and an overwhelming emphasis of economic priorities. The net result is fewer people and facilities producing more visible but more narrowly applicable results in the United States, and with more people and facilities producing less visible but more widely applicable results in Japan. In total technical power, the Japanese resource base of precision engineering is much greater than that which exists now in the United States.

Japan has its great industrial heroes. Two of them may be considered to be specialities in precision engineering. Dr. S. Inaba, president and chief executive of Fanuc, Ltd., has personally led the establishment of the company that makes more machine tool control systems than all other producers in the world together. Dr. T. Izumitani, director

of research and development of the Hoya Corporation, started the 1950s with a simple observation: the technology by which high quality optical glass was produced in the 1950s was extremely wasteful. He developed a process that increased yield from 30% to 95%, and that reduced total production time from 178 days to three days. The net result was that an industry that was unquestionably the former province of West Germany is now unquestionably the province of Japan.

A final lesson from this visit to Japan was actually learned in the weeks following my return to the United States. I became aware that there is plenty of cogent and accurate information on Japan in the available literature and other media. In fact, I could have obtained almost all the technical information I gained from this visit from just reading the available literature in American libraries. As mentioned before, Japanese PE publications nearly always have English abstracts, and a good number of translations are available from various sources. Though a fairly extensive trip is necessary to meet the people, and is sometimes needed to gain specific technical observation, a large fraction of Japanese work is freely reported in English.

APPENDIX

VISITS AND CONFERENCES ATTENDED

CONFERENCES

- Twelfth Japan International Machine Tool Fair (JIMTO), Tokyo, 30 October-8 November 1984.

This is the third largest machine tool exhibition in the world. It is organized by the Tokyo International Trade Fair Commission and is held in alternate (even) years, alternating between Tokyo and Osaka. The sponsoring agencies are MITI, the Ministry of Foreign Affairs, the Ministry of Transport, and Japanese National Railways. Cooperative (or participating) organizations include the Japan Machine Tool Builder's Association and 13 other trade associations. The two larger shows are the International Machine Tool Show (IMTS), produced by the U.S. National Machine Tool Builder's Association in Chicago in alternate (odd) years, and the European Machine Tool Exhibition, produced by the European Committee for the Cooperation of Machine Tool Industries (CECIMO) and located, alternately, in Paris, Hanover, and Milan, in alternate (odd) years. The JIMTO has about one-third the number of exhibiters as the EMO. Like the preceding IMTS and EMO shows, the JIMTO emphasis was on Flexible Manufacturing Systems with, perhaps, a stronger emphasis on precision machine tools. A definite difference between this and the other shows were the displays of FMS auxiliary equipment, such as part fixturing and manipulating equipment which can be regarded as special forms of robots, but with higher precision capabilities.

- First International Machine Tool Engineers Conference, Tokyo, 7 and 8 November 1984.

Organized by the JMTBA and held at the Tokyo Press Center Hall, this conference is the first technical meeting to be held in conjunction with the JMTO. Similar technical meetings have been recently established in conjunction with the IMTS, Chicago. This conference drew approximately 200 attendees and emphasized precision machine tool design and automated manufacturing systems.

- The Japan Society of Precision Engineering, Fall Conference, Niigata University, Faculty of Engineering.

    - Address:
      Ceramics Building, 22-17, 2-chome Hyakunincho, Shinjuku-ku, Tokyo, 160
      Tel: 03-362-4332

    - Principal Contact:
      Dr. Kentaro Yamamoto, president professor, Faculty of Engineering, Meiji University, 1-1-1 Higashimita, Tama-ku, Kawasaki-shi
      Tel: (004)-911-8181

    - Main Topics:
      Machining, metrology, CAD/CAM, FMS, robots, medical engineering, tribology.

    - Highlights:
      Meeting leaders in precision engineering in Japan.

- Comments:
  Three hundred thirty one papers were presented in three days; over 800 attendees.

VISITS

Mechanical Engineering Laboratory (Tsukuba)

- Address:
  Namiki 1-2, Sakura-mura Niihari-gun, Ibaraki-ken 305
  Tel: (0298)-54-2521, Telex: 3652570 AIST J

- Principal Contact:
  Dr. Kimiyuki Mitsui

- Main Topics:
  Research planning and management, flexible manufacturing system complex, precision machine design, diamonds turning, machine tool metrology, grinding studies, tool wear measurement, machinability studies, acoustic microscopy.

- Highlights:
  Tour of facilities.

- Comments:
  MEL has 222 people. Discussed management and Japanese government procedures in organizing a project such as the FMSC with Dr. Kanai then director of MEL. Grinding studies resulted in a library of analytical models that has since been transferred to industry (Toyoda). Developing an automated device for measuring lathe tool wear incorporating a lathe, a television monitoring tool edge between cuts and a pattern recognition scheme for recording rate and type of wear. Experimental machines being built from ceramics, including spindles. Dr. Mitsui is constructing an open C-frame, vertical spindle diamond turning machine of 0.5 m size and desires to build a 2-m-machine.

National Laboratory for High Energy Physics (KEK)

- Address:
  Ohomachi, Tsukuba-gun, Ibaraki 305
  Tel: (0298) 64-1171, Telex: 3652-534

- Principal Contact:
  Professor Dr. Kazuo Huke

- Main Topics:
  Elastic emission machining of 100 mm by 100 mm glass reflective optics for Synchrotron Orbit Radiation, measurement of figure of precise aspherics, design and construction of the Tristan 1000-m-synchotron.

- Highlights:
  Tour of the Photon Factory and Tristan experimental hall.

- Comments:
  Dr. Hongo described and showed the special apparatus built to measure the concave optic to a resolution of 10 nm. Dr. Huke explained the present light source and photon factory has a unique bandwith shifted toward the x-ray and had been used by NTT for experiments in exposing photoresist in the fabrication of large-scale integrated circuits. There are approximately 800 users of the present machine.

National Institute for Research in Inorganic Materials.

- Address:
  1-1, Namiki, Niihari-gun, Ibaraki 305
  Tel: (0298) 51-3351

- Principal Contact:
  Dr. Yasutoshi T. Hasegawa, chief researcher, consultants

- Main Topics:
  Cubic boron nitride and synthetic diamond manufacturing by means of high pressure physics, chemical vapor depositon of diamond and cubic boron nitride.

- Highlights:
  Tour of facilities, including the 30,000-ton belt press that was nearly complete and will have a specimen volume of one liter and a cross section of 125 mm.

- Comments:
  NIRIM has succeeded to date in synthesizing a 2-mm single crystal of CBN and developed the form of sintered CBN called "Transluscent CBN" which has been transferred to industry.

Electrotechnical Laboratory, Ministry of International Trade and Industry (MITI)

- Address:
  4-4-1 Umezono, Sakura-mura Niihari-gun, Ibaraki
  Tel: (0298) 54-5311

- Principal Contact:
  Dr. Masayuki Ikeda, chief of fabrication technology section

- Main Topics:
  Lasers in manufacturing, precision grinding of metals and glasses.

- Highlights:
  Discussion of use of lasers in MITI's experimental FMS project.

- Comments:
  Dr. Ikeda directs, for MITI, the laser portion of the FMC project. His private technical interest is in following his interest in using fixed abrasives for precision finished fabrication of optical components and such.

National Research Laboratory of Metrology, Agency of Industrial Science and Technology, Ministry of International Trade and Industry (MITI)

- Address:
  1-4, 1-chome, Umezono, Sakura-mura Niihari-gun, Ibaraki 305
  Tel: (0298) 54-4041

- Principal Contact:
  Dr. Yoshihisa Tanimura

- Main Topics:
  Surface metrology and national standards, developments in metrology.

- Highlights:
  Meeting with Tanimura and Professor J. Nara, chairman of Japanese surface texture standards committee.

- Comments:
  Dr. Tanimura had spent one year at the U.S. National Bureau of Standards in 1975. Japanese do not seem as anxious as U.S. and others to update surface texture standards.

Mazda Motor Corporation

- Address:
  3-1, Shinchi, Fuchu-cho, Aki-gun, Hiroshima
  Tel: (082) 282-1111, Telex: 654204 MAZDA J, Cable: MAZDA HIROSHIMA

- Principal Contact:
  Dr. Hisashi Togii

- Main Topics:
  Automobile manufacturing, diesel engine manufacturing, machine-tool design and manufacturing, CAD/CAM, precision grinding.

- Highlights:
  Tour of four-cylinder diesel manufacturing plant and the "halls" where they develop, design, and build the "Toyo" line of machine tools.

- Comments:
  Mazda is 40% owned by Ford. It is the only engine company simultaneously making their own diesel, reciprocating and rotary gasoline engines. The Wankel engine problems seem to have been solved. Mazda contracts out approximately 40% their machining. (I learned, after returning to the U.S. that Deere has formed a joint venture with Mazda to exploit Wankel engines.) Toyo concentrates on internal grinding machines, but also build a line of machining centers. They develop their own special controls and have developed a mini-DNC system that they showed at the Tokyo machine tool show. The system I saw can control 15 machines. One machining center can store four-part programs which the operator can select by switch.

Mitsubishi Heavy Industries, Ltd., Hiroshima Technical Institute

- Address:
  6-22, 4-chome, Kan-on-shin-machi, Nishi-ku, Hiroshima 733
  Tel: (082) 291-2111

- Principal Contact:
  Dr. of Engineering, Yasuro Takahashi, deputy general manager

- Main Topics:
  General research activities of MHI.

- Highlights:
  Tour of institute, including process control software development, materials and metallurgy laboratory, vacuum processes laboratory, desalinization prototype facility, ceramics laboratory, coal gasification and coal liquefaction pilot plants, and environmental studies laboratory.

- Comments:
  Hiroshima is one of five MHI technical institutes. The others are at: Nagasaki, Takasago, Yokohama and Nagoya. Their laboratories are very well equipped with large pieces of the latest kind. There are 200 degreed "specialists" in a total of 370 people plus 250 people in contractor "subsidiaries." Five to ten% of the work is funded by the Japanese government.

Mitsubishi Heavy Industries, Ltd., Hiroshima Machine Tool Works

- Address:
  540, Minamishimoyasu, Gion-cho, Asa-Minami-ku, Hiroshima 731-01
  Tel: (082) 874-3111

- Principal Contact:
  Mr. Shigeru Kiriyama, general manager

- Main Topics:
  Machine tool design and manufacturing.

- Highlights:
  Tour of plant.

- Comments:
  This plant concentrates on large machine tools and machining centers. Mr. Suzuki, who conducted the tour, was discouraged about the future of large machines. They were completing construction of a 13 m by 30 m gantry-type milling machine for "Japanese atomic energy research." A new oil hydrostatic spindle is being introduced to operate at 10,000 to 20,000 rpm, about the same size and weight as ball-bearing spindles. They are also introducing a ball-bearing spindle for small machines in which a thermophile is used to reduce thermal effects.

Hiroshima University

- Address:
  Shitami, Saijo, Higashi Hiroshima 724
  Tel: (0824) 22-7111

- Principal Contact:
  Dr. Norihiko Narutaki, professor, Department of Mechanical Engineering

- Main Topics:
  Cutting tool research, whisker-reinforced metals and other materials, sintered materials research, high strain rate forming and triaxial stress testing, wear testing, engineering education.

- Highlights:
  This was my first opportunity to see the typical Japanese academic unit: professor, assistant and associate professors, graduate students, and undergraduate students organized and located together and near laboratories. I was included in a reception for 50 Hiroshima businessmen who were there at the invitation of the Dean of Engineering to tour and discuss possible projects of mutual interest. These were mostly small manufacturers who did not percieve that they had much in common with the university. There were a few exceptions, however.

- Comments:
  Professor Narutaki is conducting a variety of studies on material removal by various processes, single point turning, milling and grinding. He has worked on cubic boron nitride tools and grinding wheels, and is now especially interested in machining ceramics. The work on sintered materials concentrates on measuring resultant material properties. I heard complaints that Japan does not have enough interest in the whisker-reinforced materials. Science and engineering departments are located in relatively new facilities on a site about one hour away from the main downtown campus.

Saitama University

- Address:
  255 Shimo Okubo, Urawa 338
  Tel: (0488) 52-2111

- Principal Contact:
  Dr. Akira Kobayashi, professor, Department of Mechanical Engineering

- Main Topics:
  Diamond turning, grinding, polishing and laser-assisted chemical milling, drilling, rolling element bearing theory and design, and air-bearing theory and design.

- Highlights:
  Tour of Professor Kobayashi's laboratory, discussion of diamond turning (flycutting) of plastics, Dr. Kasai's work on face grinding in which near specular (10 nm Rmax) surfaces are obtained and his work on noncontact polishing. They have a 20 keV argon ion source with which it is intended to work on sharpening of diamond tools.

- Comments:
  Professor Kobayashi is a national leader in pursuing precision machining. Dr. Kasai has received two medals for his work.

Japan Machine Tool Builder's Association

- Address:
  3-5-8, Shibakoen, Minato-ku, Tokyo
  Tel: (03) 434-3961, Telex: 22943 MATOOLAS J, Fax: (03) 434-3763

- Principal Contact:
  Mr. Shinshichi Abe, executive director

- Main Topics:
  Machine tool research, international competition and possible collaboration.

- Highlights:
  None.

- Comments:
  This was perhaps the least productive of my visits in Japan. I suggested that I meet with members or committees but nothing resulted.

Kanazawa University

- Address:
  Kanazawa, 920

- Principal Contact:
  Dr. Tsuguo Kohno, professor, Precision Engineering Department, Faculty of Engineering
  Tel: 0762-61-2101

- Main Topics:
  Surface metrology, displacement measurement, contour inspection, cutting studies using a scanning electron microscope.

- Highlights:
  Seeing Professor Kohno's optical surface topography sensor, discussions with Professor Sugita and Dr. Ueda on cutting studies.

- Comments:
  Professor Kohno's invention has a resolution of about one nanometer and is now made by Olympus and marketed as part of a step-height instrument sold by Kosaka Laboratory, Ltd. Dr. Ueda demonstrated his SEM cutting studies in which he is concentrating on amorphous materials. Results show lamellar formation in real time.

Nippon Kogaku K.K. (Nikon, two visits)

- Address:
  Ohi Plant 6-3, 1-chome, Nishi-Ohi Shinagawa-ku, Tokyo 140
  Tel: 03 (773) 1111, Telex: 22601 NIKON J

- Principal Contact:
  Dr. Hiroshi Hashimoto, manager, research and development, Manufacturing Engineering Department

- Main Topics:

Diamond turning, design of diamond turning machines, precision grinding and optical polishing.

- Highlights:
  Discussion of Nikon's own design of diamond turning and grinding machines and polishing machine.

- Comments:
  Dr. Hashimoto has collected a most impressive group of young engineering graduates from Japan's leading schools: Osaka, Kyoto, and Toyohashi. Nikon's designs and builds its own machines using concepts that are unique to them. For example, their designs are entirely based on air bearings.

Toshiba Corporation

- Address:
  8, Sinsugita, Isogo-ku, Yokohama 235

- Principal Contact:
  Mr. Noriyuki Tanaka, general manager, Manufacturing Engineering Laboratory

- Main Topics:
  Diamond turning, laser machining and material treatment, robot assembly of electronics (PC boards), robot accuracy.

- Highlights:
  Tour of precision engineering, laser technology, and robot technology laboratories.

- Comments:
  Dr. Sumiya made copper mirrors for the high powered lasers in MITI's FMC project (for Dr. Ikeda). Copper mirrors are now used on Toshiba's 20 kW carbon dioxide commercial laser. Robots are designed just to perform special functions needed by Toshiba. Laboratory includes a robot accuracy test bed using television to measure three-dimensional position.

Keio University

- Address:
  3-14-1, Hiyoshi Kohoku-ku, Yokohama-shi
  Tel: 044-63-1141

- Principal Contact:
  Dr. of Engineering, Ichiro Inasaki, professor, Department of Mechanical Engineering, Faculty of Science and Technology

- Main Topics:
  Cutting, grinding, machine components.

- Highlights:
  Acoustic emission demonstration in laboratory.

- Comments:

Keio is a private university. Consequently, Professor Inasaki receives support for his research from industry and government, and can do proprietary research. He has developed a drill breakage detector based on acoustic emission that is marketed by Nachi. He has developed an aerostatic lead screw, and has one of the first creep grinding machines built in Japan and is working on automatic dressing of wheels.

Yokohama National University

- Address:
  Tokiwadai, Hodogaya-ku, Yokohama, 240

- Principal Contact:
  Dr. Kazuo Nakayama, professor, Department of Mechanical Engineering

- Main Topics:
  Real time measurement of grinding wheel wear, chip breaking, tool wear studies.

- Highlights:
  Tour of laboratory where I saw contact-type wheel wear sensors with teflon contact pads.

- Comments:
  This laboratory has a well-equipped shop that reminds me of Stanford University.

Ogihara Iron Works Co., Ltd.

- Address:
  891, Higashiyajima, Ota City, Gunma
  Tel: 0276-38-1221, Telex: 03473-406, Int'l Fax: 0276-38-1341

- Principal Contact:
  Mr. Eiichi Ogihara, president

- Main Topics:
  Design and manufacture of car body panel dies, CAD/CAM, development of flexible manufacturing system.

- Highlights:
  Tour of plant with president of U.S. National Tooling and Machining Association and presidents of two of largest tool and die companies in U.S.

- Comments:
  Ogihara is the largest and finest independent tool and die company in the world and is family-owned with about 1000 employees. Customers are 80 automobile manufacturers in 28 countries. The company's plan is to automate the production of dies to the highest degree possible. Their new facilities provide for computer-aided design of the dies and the patterns with which they are cast. A CALMA/CAD system, coupled with machining centers and large DEA measuring machines allow Ogihara to start with a customer's drawings or a model from which the die is designed. Polystyrene patterns are generated using a large machining center. They do their own casting, using a dry sand mold.

The castings are removed from the mold, cleaned, and palletized for final machining in a FMS installed with Okuma machining centers. The system can handle dies weighing 80 tons. Dies are currently handfinished (polished) but Professor Nakagawa at the University of Tokyo is developing a robot for this purpose. Ogihara has the full capability to demonstrate the dies in factory operation as well as to assemble and weld a complete car body. They are currently working on their own CAM system.

Toyo University

- Address:
  2100 Nakanodai Kujirai, Kawagoe, Saitama 350
  Tel: 0492-31-1211

- Principal Contact:
  Kunio Uehara, professor of mechanical engineering, Faculty of Engineering

- Main Topics:
  Heat assisted machining of hard materials, grinding studies.

- Highlights:
  Tour of laboratory.

- Comments:
  Heating during cutting is done by passing the current through the tool. They have built a recent Mazak machining center in laboratory.

Utsunomiya University

- Address:
  2753, Ishii-cho, Utsunomiya 321
  Tel: 0286-61-3401

- Principal Contact:
  Dr. of Engineering, Hiroshi Eda, associate professor, mechanical engineering, Faculty of Engineering

- Main Topics:
  Diamond turning (flycutting), cutting studies of ultrapure materials, CBN grinding.

- Highlights:
  Tour of laboratory.

- Comments:
  Pure materials being studied are 99.99% pure aluminum and copper. They are also studying pure solid solutions. There is some collaboration with the Phillips Eindhoven laboratory, and the head of the group is Professor Kishii who is responsible for forty students.

Kumamoto University

- Address:
  Kurokami 2, Kumamoto, 860
  Tel: (0963) 44-2111

- Principal Contact:
  Dr. T. Matsuo, professor of production engineering department

- Main Topics:
  Grinding, cutting tool testing.

- Highlights:
  Tour of laboratories.

- Comments:
  Kumamoto is a solid school of design, manufacturing and production engineering, making a transition to the computerized world, and has a new department of information systems.

Hokkaido University

- Address:
  Nishi-8, Kita-13, Kita-ku, Sapporo, 060
  Tel: 011-711-2111, Ext. 6435

- Principal Contact:
  Dr. Katsumasa Saito, professor, Department of Precision Engineering, Faculty of Engineering

- Main Topics:
  CAD/CAM, robots, EDM of complex shapes, metrology.

- Highlights:
  Tour of laboratories.

- Comments:
  This was actually two visits, one with Professor Saito and the other was with Professor Okino who is reputed to be Japan's leading expert in CAD/CAM. Work on CAD/CAM has been underway since 1967 and has been concentrated on solid modeling as the basis for part descriptions. Professor Okino once headed a large ($800,000) project on CAD/CAM. Professor Saito is very active promoting Hokkaido small business with MITI. Dr. Miyoshi, of Professor Saito's group, is developing novel contact and noncontact sensors for metrology. Dr. Kishinami, also of Professor Saito's group is concentrating on software and hardware for mold making, some of which has already been commercialized.

Toyohashi University of Technology

- Address:
  1-1 Hibariga-oka, Tenpaku, Toyohashi 440
  Tel: 0532-47-0111

- Principal Contact:

Dr. Tetsutaro Hoshi, professor, Department of Production Systems

- Main Topics:
  High performance cutting tools, grinding, machine design, vibration control, machine and process control systems.

- Highlights:
  Tour of facilities.

- Comments:
  Toyohashi is one of the newest technical universities in Japan, opened only eight years ago and most students are upper division or graduate level. English capability is a high priority here. Professor Hoshi has recently been working with private companies on machine designs incorporating epoxy concrete and two of his designs have been marketed. Professor K. Yamazaki is concentrating on mechatronics. Students learn to design systems from the chip up. An Intel chip that is not yet on the market was being used by a student to develop a servo motor control device. Professor Horiuchi is conducting several projects in parallel all addressing the improvement of grinding including actively controlling vibration, sensing and recognizing spark-out to cause more rapid convergence.

Yamazaki Machinery Works, Ltd. (Mazak)

- Address:
  Oguchi-cho, Niwa-gun, Aichi Prefecture, 480-01
  Tel: (05879)-5-1131, Fax: (05879) 5-2717, Telex: 59777 J, Cable: MAZAK NAGOYA

- Principal Contact:
  Mr. Akimitsu Nagae, director, advanced technology development

- Main Topics:
  Flexible manufacturing systems, automated factory, CAD/CAM.

- Highlights:
  Visit to Minokamo plant.

- Comments:
  Mazak is the fastest growing machine tool company in Japan. Its Minokamo plant is a model for state-of-the-art automation. Minokamo is about 50,000 square meters on a new site that permits expansion to three times this size. Machine tools are built here by a total staff of three hundred, half of which are employed in assembly. The plant operates unattended one shift. The home office is the site of their CAD system which is Lockheed's CADAM and which is connected to Minokamo by three telephone lines. Mazak employs 2400 people, 250 of whom are engineers.

Okuma Machinery Works, Ltd.

- Address:
  Oguchi-cho, Niwa-gun, Aichi Prefecture, 480-01

Tel: (05879) 5-7111, Telex: 4573310 OKUMA J

- Principal Contact:
  Design, FMS, computer integrated manufacturing.

- Highlights:
  Tour of lathe assembly plant, mechanical engineering laboratory, electronics engineering laboratory.

- Comments:
  Okuma has 1800 employees, 450 are in engineering departments. Okuma thinks of itself as a "single source" mechatronics company, making its own electronics and machine tool hardware. They installed their own first FMS in their lathe factory. Output is about 50,000 units per year. Development work includes experiments with epoxy concrete and other synthetic structural materials, cutting tool evaluation. They have experimented with varieties of cubic boron nitride with encouraging results. Okuma exhibited a lathe with diamond turning capability at the Tokyo show in November. The machine was equipped with a headstock partially constructed of epoxy concrete to improve stablility.

Nishijima Machining System

- Address:
  2-12-5 Higashiwaki Toyohashi-City, Aichi Prefecture
  Tel: (0532 31-8111, Fax: (0532) 31-1818

- Principal Contact:
  Mr. M. Nishijima, president

- Main Topics:
  Small flexible manufacturing systems, machining centers, CAD/CAM, Soviet and Eastern Bloc machines, operation of small manufacturing company in Japan.

- Comments:
  Designs and manufactures machining centers and flexible manufacturing systems for small parts. They have design of FMS especially for limited floor space; domestic market only. It is small, 100 people, and family-owned company. The president's son has spent six years in West Germany studying economics and engineering. The president's nephew is currently conducting joint contol system development at Toyohashi University of Technology. The company first developed its own CAD system and is now installing Lockheed's CADAM system and does its own electrical/electronic fabrication and own control systems. Half of the employees have some kind of engineering degree, and they use advanced metrology, and other engineering design techniques. They can deliver machining center fourteen weeks from receipt of order.

Kobe University

- Address:
  Nada, Kobe 657
  Tel: 078-881-1212

- Principal Contact:
  Dr. Kazuaki Iwata, professor, Department of Mechanical Engineering

- Main Topics:
  Diamond machining, general metal cutting, adhesion, manufacturing systems, production scheduling, machine tool design, ergonomics.

- Highlights:
  Visit to laboratories, graduate research center.

- Comments:
  Professor Iwata is very well known in the U.S. and had spent two years (1966-68) at the University of Wisconsin. His associate, Dr. Moriwaki (now also a full professor), is conducting studies of diamond tool wear and performance using a machine built by Tcshiba and acoustic emission instrumentation. An interesting project that is conducted interdepartmentally in the graduate research center concerns study of motions of human bodies and the construction of analytical tools with which to study the stresses on joints, bones and in muscles.

Sumitomo Electric Industries, Ltd.

- Address:
  1-1-1, Koya Kita, Itami-City, Hyogo Prefecture 664
  Tel: (0727) 81-5151, Telex: 5326416

- Principal Contact:
  Dr. Akio Hara, general manager, Super Hard Materials Division

- Main Topics:
  Diamond and cubic boron nitride tool materials.

- Highlights:
  Tour of Sumitomo's display room.

- Comments:
  Sumitomo has developed synthetic single crystal diamond tool materials they feel are superior and more consistent than natural stones. An informal arrangement was made for LLNL to evaluate sample tools. A similar arrangement already exists to evaluate Sumitomo's transluscent CBN.

Matsushita Electric Industrial Company, Ltd., Wireless Research Laboratory

- Address:
  1006, Oaza-Kadoma, Kadoma-shi, Osaka, 571
  Tel: (06) 908-1291, Telex: 5297220

- Principal Contact:
  Councilor Ken-Ichi Hirai

- Main Topics:
  Molding of plastic lenses, antireflective coatings for plastic lenses.

- Highlights:
  Tour of lens moldmaking, molding, and coating facilities.

- Comments:
  Matsushita successfully injection molds grossly aspheric plastic lenses for color television projectors. They use an American-made machine for making the precision molds.

Osaka Diamond Industrial Company, Ltd.

- Address:
  80, Ohtori Kitamachi 2-cho Sakai, Osaka, 593
  Tel: (0722) 62-1061, Telex: 5374783 OSK DIA J, Fax: 0722-64-4881

- Principal Contact:
  Dr. M. Tamaoki, president

- Main Topics:
  Diamond tools.

- Highlights:
  Discussion of measuring the qualities of diamonds tools and tool fabrication.

- Comments:
  This discussion resulted in the proposal of a joint project between Osaka University (Professor Ikawa) and LLNL to use the LLNL Precision Engineering Research Lathe (PERL) to relate measured properties to tool performance and test theories developed by Ikawa.

Fanuc, Ltd.

- Address:
  3580, Shibokusa Aza-komanba Oshino-mura, Minamitsuru-gun, Yamanashi Prefecture 401-05
  Tel: 055584-5500, Telex: 3385-401, Fax: 055584-5510

- Principal Contact:
  Dr. of Engineering, S. Inaba, president and chief executive officer

- Main Topics:
  Machine tool controls, robots, plastic injection molding machines, EDM.

- Highlights:
  Visit to Fanuc's new factory and discussion with Dr. Inaba.

- Comments:
  Fanuc had occupied its new factory at the foot of Mt. Fuji just three months before my visit. The newness, spaciousness, and ultramodern quality of the facilities were most impressive. Fanuc reportedly is concentrating on making stand-alone machine tool control and not on entering CAD/CAM. They have diversified into plastic injection molding machines with a license from Cincinnati Milacron, also, has a joint venture in robots with General Motors

and, with Siemens, owns General Numeric in the U.S. Dr. Inaba commented that work needs to be done to improve the technology of DM.

Toshiba Machine Company, Ltd. (Shibaura)

- Address:
  Numazu Plant 2068-3 Ooka, Numazu-shi, Shizuoka-ken 410
  Tel: (0559) 21-5240, Telex: 3922401 TOKISO J

- Principal Contact:
  Mr. Koya Kimura, director and general manager, engineering laboratory

- Main Topics:
  Diamond turning machines, aerostatic spindles, grinding, electron beam photoresist exposure machines.

- Highlights:
  Visit to diamond turning and precision machine building facility.

- Comments:
  Toshiba is the largest machine tool builder in Japan. They also manufacture food machinery, injection molding machines and printing presses. The precision machining facility contains first-class machines from all over the world. The machine tool erection technology resembles that of the Moor Special Machine Company of Bridgeport, Connecticut, from whom, in fact, it was learned. During the tour of the factory, a 10.5 m vertical boring mill under construction was observed. Shibaura produces an aerostatic spindle of unique design which it sells with or without built-in motor for use on special machines such as contact lens turning machines.

Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation

- Address:
  Musashino-shi, Tokyo 180
  Tel: (0422) 59-2633

- Principal Contact:
  Yoshiyuki Ueno, chief of material processing technology section, technology division

- Main Topics:
  Silicon wafer polishing, dry lubrication, small robots, laser-assisted etching.

- Highlights:
  Tour of laboratories

- Comments:
  I was shown an automated polishing machine that polishes four or five wafers at one time to 1 μm flatness and 10 Å rms finish at a rate of 300 per hour. I also saw a noncontact waver polishing machine using rubber tool, hydrodynamic flotation of part. Dry lubricant is molybdenum disulfide deposited using a 2 to

5 keV argon or nitrogen beam on a rotating target of both Mo and S arranged on surface in pie slice shapes. Application is bearings for use in space.

Hitachi Seiko, Ltd.

- Address:
  2100 Kami Imaizumi, Ebina-shi, Kanagawa 243-04
  Tel: (0462) 31-7111, Telex: 03872-233 SEIKO J

- Principal Contact:
  Mr. Mitsuo Hashimoto, director manager, design department

- Main Topics:
  Precision machine design, diamond turning, precision grinding.

- Highlights:
  Tour of facilities, memory disc diamond turning machines.

Comments:
Hitachi Seiko has approximately 900 people and does about $120 million of business per year, 70% in machine tools. The facility visited was opened in 1980. They also build ECM and EDM machines, and their output is about five diamond turning machines per month. I saw a spindle design incorporating air cooling with heat pipes to reduce thermal effects.

Atsugi Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation

- Address:
  1839, Ono, Atsugi-shi, Kanagawa, 243-01
  Tel: (0462) 40-2400

- Principal Contact:
  Mamoru Kondo

- Main Topics:
  Fabrication of integrated circuits.

- Highlights:
  Tour of super clean prototype automated production facilities.

- Comments:
  Discussion centered on line width and resolution possibilities. Limits are defined by molecular size of photoresist, which is about 100 Å, and exposing beam spot size. They are experimenting with x-ray exposure. Dr. Kondo directed the experiment using the HEP(KEK) source at Tsukuba. They are also attempting to develop an x-ray source based on z-pinch plasma. I also saw an "electron cyclotron resonance" coating machine which coats at approximately room temperature, no substrate heating required.

Seiko Seiki Company, Ltd.

- Address:
  3-1, Yashiki, 4-chome, Narashino-shi, Chiba 275
  Tel: 0474-75-3111, Telex: 2983-335 SEIKOS, Fax: 0474-78-8644

- Principal Contact:
  Mr. Sadao Moritomo, managing director, executive manager of manufacturing headquarters

- Main Topics:
  Design of precision grinders, turbomolecular vacuum pumps and magnetic bearings.

- Highlights:
  Meeting of Ultraprecision Machining Committee of JSPE and tour of factory.

Comments:
Seiko Seiki concentrates on internal centerless grinders for products like precision bearings. They design special grinders for their own use and for sale. One special design grinds the cavity for a sliding-vane automobile airconditioning compressor, which it also manufactures. It uses a 200,000 rpm ball bearing spindle with oil mist lubrication with a light-pipe sensor to sense lubrication interruption. Seiko Seiki has license to exploit the S2M (France) magnetic bearing in Japan. Some machines are equipped with adaptive control of grinding force, a Marposs sensor to signal when to dress grinding wheel.

Osaka University (Two visits)

- Address:
  Suita, Osaka 565
  Tel: (06) 877-5111

- Principal Contact:
  Dr. of Engineering, Naoya Ikawa, professor, Department of Precision Engineering

- Main Topics:
  Diamond tools, polishing, machine tool metrology.

- Highlights:
  Discussion of properties of diamond tools and cutting mechanics, visits to laboratories, float polishing machine, elastic emission machine.

Comments:
Professor Ikawa's group, formerly led by the venerable, retired Professor Tsuwa, is doing outstanding basic research in diamond tools, ultraprecise polishing and applications to high technology components such as substrates for VLSI. Professor Namba is especially recognized for his "float polishing" and Professor Mori for his "elastic emission machining" developments.

Institute of Laser Engineering

- Address:

Osaka University 2-6 Yamadaoka, Suita, Osaka 565
Tel: (06) 877-5111, Telex: 5286228

- Principal Contact:
  Professor Dr. Chiyoe Yamanaka, director

- Main Topics:
  Glass laser design and construction, diamond turning, optical element fabrication.

- Highlights:
  Tour of GEKKO-12.

- Comments:
  ILE is one of the world's leading laboratories in the research and development of laser fusion energy. GEKKO-12 was the world's most powerful laser until the Lawrence Livermore National Laboratory's NOVA laser was finished in December 1984. ILE's next proposed laser experiment is KOHNGO, a 50 arm, 100 kJ machine.

Toyoda Machine Works, Ltd.

- Address:
  Kariya-City, Aichi Prefecture
  Tel: (0566) 22-2211, Fax: (0566) 22-7214, Cable: TOYODKOKI KARIYA

- Principal Contact:
  Dr. Ryuji Wada, managing director

- Main Topics:
  Diamond turning, polishing.

- Highlights:
  Tour of facilities with Mr. Norman Brown and Dr. T. Saito from LLNL.

Comments:
  Toyoda makes diamond turning machines for special purposes such as cylinders for copiers, polygons for scanner mirrors, magnetic recording discs and a two-axis machine for general purpose (optics, etc.). Professor Namba's float polishing machine is built and sold by Toyoda, primarily for the electronic and video cassette recorder industries. Toyoda engineers have a strong preference for oil hydrostatic bearings.

Hoya Corporation

- Address:
  572 Miyazawa-cho, Akishima-shi, Tokyo
  Tel: (0425) 41-3131, Telex: 26585 HOYAGW J

- Principal Contact:
  Dr. Tetsuro Izumitani, managing director, R&D laboratories

- Main Topics:
  Continuous manufacture of high quality lens blanks from raw materials, glass chemistry and fabrication processes including grinding and polishing, molding of finished aspheric glass lenses to sizes of 150 mm, diffraction limited.

- Highlights:
  Tour of automated glass lens making plant.

Comments:
  Dr. Izumitani explained how, over the past 20 years, the production of high-grade optical glass had been reduced by automation from 178 days production time to only three days.

Hitachi Central Laboratory, Hitachi, Ltd.

- Address:
  Kokubunji, Tokyo 185
  Tel: (0423) 23-1111, Telex: 2832522 CHUKEN J

- Principal Contact:
  Dr. of Engineering, Tetsuzo Matsunaga, manager, prototype development Department

- Main Topics:
  Diffraction gratings, diamond machining of synchotron orbital radiation mirrors, video disc fabrication.

- Highlights:
  Tour of facilities.

Comments:
  HCRL has 1200 employees of which 870 are classified as researchers. I was shown the grating work by Mr. Tatsuo Harada and the diamond machining by Mr. Shigeo Moriyama. Some of the grating work is directed at astrophysics instrumentation, some for U.S. experiments. The aspheric generator is a flycutting machine equipped with a peizoelectric fast tool driver.

University of Tokyo, Institute of Industrial Science

- Address:
  22-1, Roppongi 7-chome, Minato-ku, Tokyo 106
  Tel: 04-402-6232, Ext. 2230

- Principal Contact:
  Dr. of Engineering, Hisayoshi Sato, professor

- Main Topics:
  Surface metrology, magnetic-assisted polishing, composite materials, precision part transporters-positioners for FMS, robot polishers, fabrication of metal whiskers, ceramic grinding, motor control, hysteresis motors, noncontact diameter measurement in real time, magnetic bearings, laser cut laminated die substrates with cooling passages.

- Highlights:
    Tour of laboratories, and meeting outstanding researchers.

Comments:

This was the most impressive, varied, aggressive array of highly qualified technologists I met in Japan. Professors Sato, Imanaka, Harashima, Nakagawa, Higuchi, and others, collectively and individually, displayed a startling variety of activities and novel developments. Research is more applied than basic and obviously has near-term relevance to commercial application.

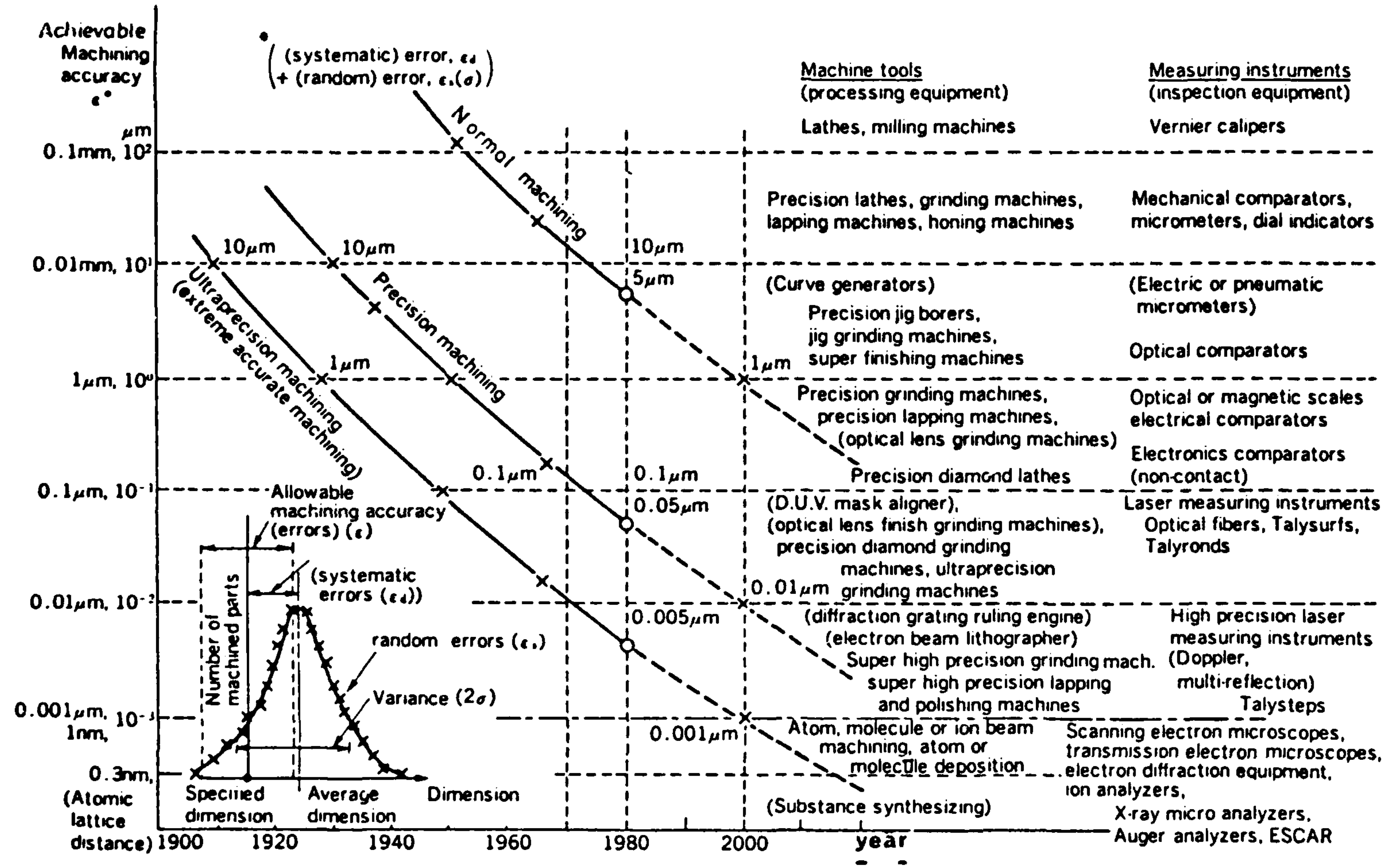


Figure 1. Historical and possible future development of achievable machining accuracies. (With permission of N. Taniguchi.)

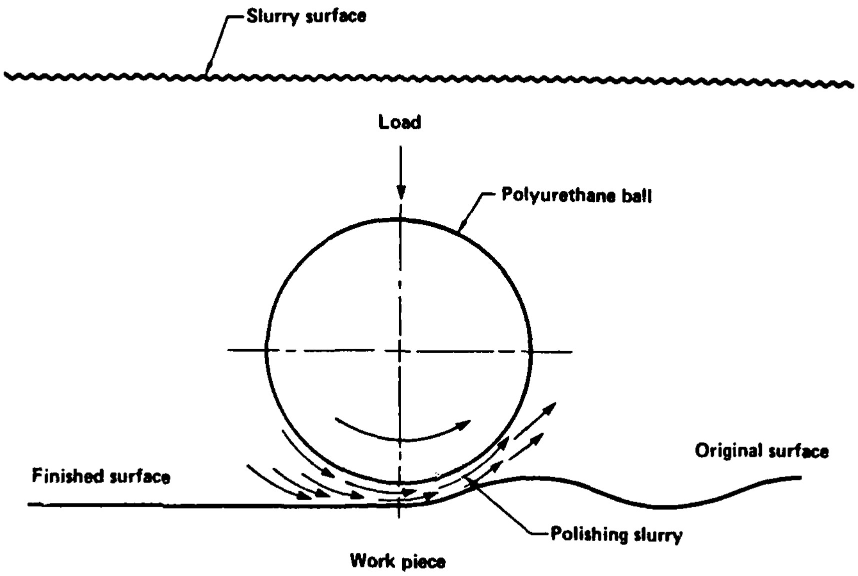


Figure 2. Schematic of elastic emmission machining process.

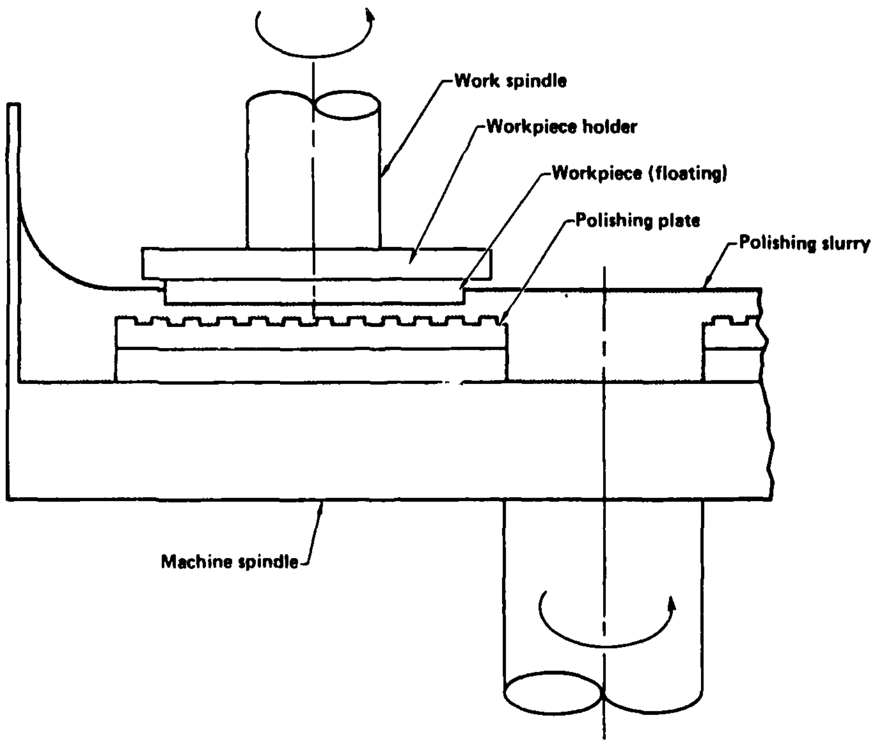
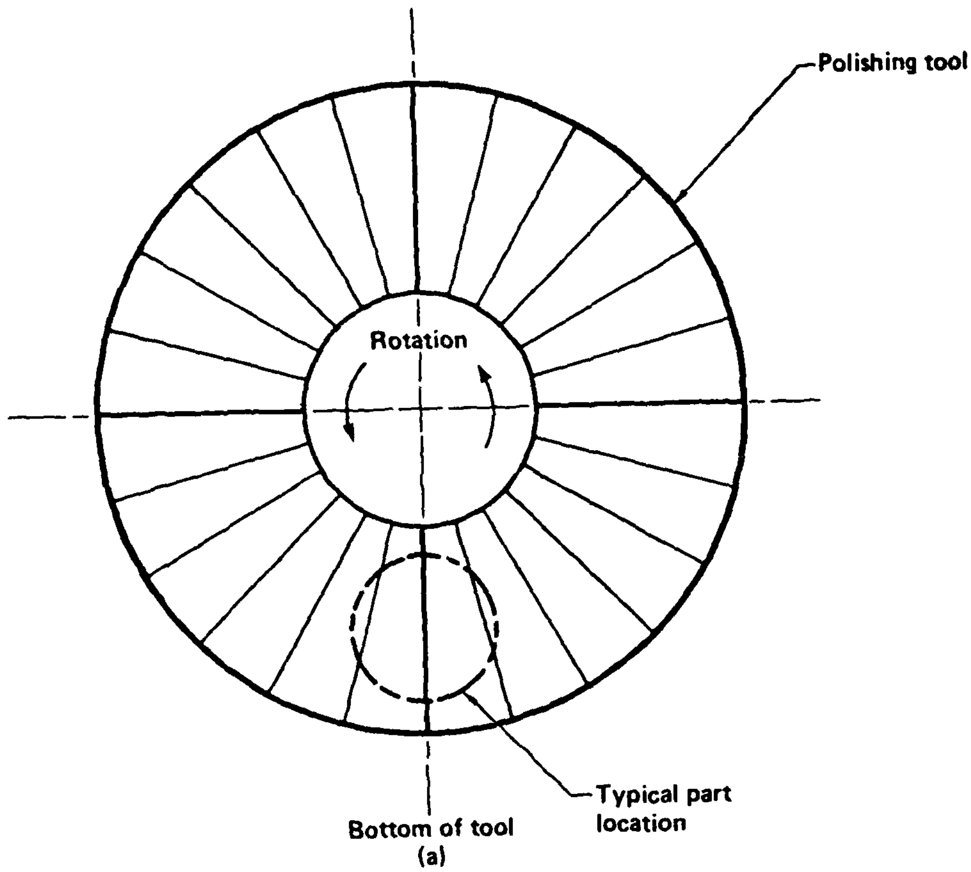


Figure 3. Schematic of a "float polishing" process.



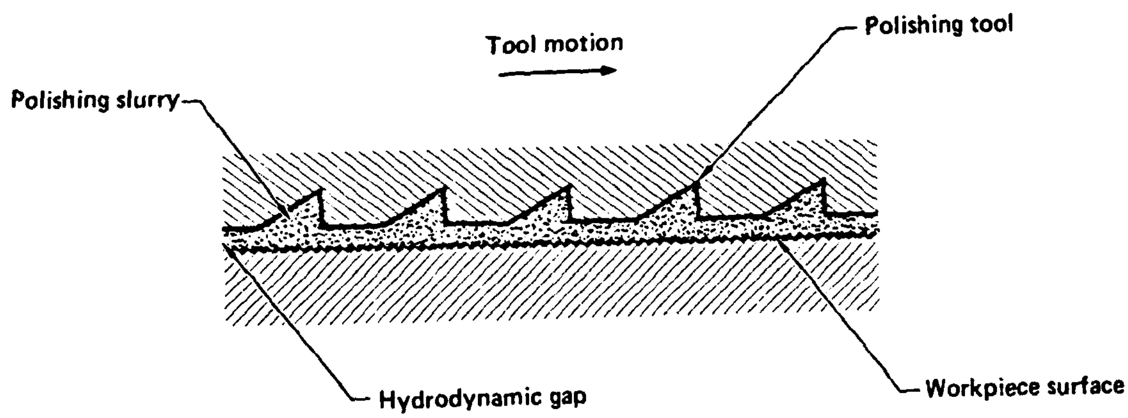


Figure 4. Noncontact polishing technique used at Musashino ECL:
(a) Bottom of tool
(b) Gap cross-section

A REPORT ON VLSI TECHNOLOGY AS PRESENTED AT THE 1985 INTERNATIONAL SYMPOSIUM ON VLSI TECHNOLOGY, SYSTEMS AND APPLICATIONS, TAIPEI, TAIWAN

S. Ashok

INTRODUCTION

Taiwan's entry as a strong contender in VLSI technology and applications was amply demonstrated by the highly successful International Symposium on VLSI Technology, Systems and Applications held in Taipei during 8-10 May 1985. Scheduled to precede the 1985 VLSI Symposium in Kobe, Japan, this meeting attracted an audience of over 800 people with wide international participation, the largest overseas contingent being from the U.S.A., followed by Japan, West Germany, France, Canada, U.K., The Netherlands and South Africa. Following keynote addresses by Gene Amdahl of Trilogy and Frank Moore of IBM Corporation, 74 papers were presented in ten sessions encompassing memory, testing, technology, design systems, metallurgy and circuit techniques, design synthesis, devices, algorithms and architecture, thin dielectrics and custom chips. Four of these ten sessions were devoted to the technology of VLSI, with the keynote address by Amdahl on the "Mainframe Technology for the Next Decade" setting the stage for the succeeding sessions. The following is a summary of the main results presented at the above sessions.

SYMPOSIUM SUMMARY

G. Amdahl, in his keynote address, speculated on the important VLSI technologies for the next decade based on fundamental limitations as well as circuit packing complexities. He concurred with the industry-wide faith in CMOS for small and intermediate mainframes, while seeing no serious rival for emitter coupled logic (ECL) in the high-performance mainframes. Based on recent trends in feature size and die size, 150 K gate chips were projected by the end of the decade, resulting in 4 MB memory chips. The potential of GaAs for simple logic structures could not be ignored, but a two-three year lag in feature and chip sizes relative to Si exists at the moment. The importance of packaging technology in preserving the performance of the chips in systems was stressed, and the multilayer ceramic printed circuit structure (Thermal Conduction Module) developed by IBM was cited as a singular achievement. The use of SiC by Hitachi for packaging was also held out promising due to the close thermal expansion match with Si.

- Technology

The first paper in the session "Technology" by T. Nakagawa *et al.* of Fujitsu, Ltd., dealt with sputtered thin film disks for high-density recording. It was pointed out that, while in the last 15 years the areal recording density has been doubling every two and one-half years, the limitations in magnetic disk recording are yet to be established. Sputtered-Fe_2O_3 thin film disks together with thin film heads at practical head-to-disk spacings were shown to have attained recording densities of over 23 kFCI (kilo f' ıx changes per inch). Even higher densities (70 kFCI) have been seen with double-layer CoCr rigid disks, and the limitations on high density are held to be practical design problems such as operation at submicron head flying heights.

Impressive results on 3D device structures using silicon-on-insulator (SOI) technology were reported by K. Sugahara *et al.* from the Mitsubishi LSI research and development laboratory. Selective laser recrystallization of polysilicon deposited on silicon nitride

strips resulted in vertically integrated MOSFETs in a triple level structure. Enhancement mode devices have been obtained at all the three levels, with acceptable field effect mobilities. The crystal quality is found suitable for LSI at the first and second levels, while device uniformity needs to be improved at the third level.

H. H. Wang *et al.* of Hewlett-Packard described three plasma etching modules developed for a double metal CMOS VLSI process. By using the differential etch reaction between F and Si and recombination reaction between F and C in an (SF_6 + 10% Freon 11) plasma, poly Si gate anisotropic etching gives an undercut of less than 0.15 μ per side. Step heights and step angles have been reduced with a resist etchback planarization module, leading to reduced *via* depth over islands and fields as well as elimination of metal shorts due to hillocks.

A novel use of amorphous Si (a-Si) in VLSI technology was described by H.-M. Shih *et al.* of Amdahl Corporation. They replaced poly Si (p-Si) with LPCVD a-Si and thereby reduced oxide-induced dislocations as well as stacking faults. The sheet resistance of boron-implanted a-Si is also found to be lower than that of p-Si by a factor of 2.5 to 3. The potential VLSI application of a-Si followed by high-pressure oxidation (HIPOX) is thought to be in self-aligned contacts and low-resistance extended electrodes, and in improving metal step coverage.

The results of a joint effort by researchers at the National Chiao Tung University and the Industrial Technology Research Institute (ITRI), Hsinchu, Taiwan, on a new VLSI field isolation process was presented by H. H. Tsai *et al.* By using a thin nitrided oxide layer as a stress-relief buffer layer and as an interface sealing layer for local oxidation enhancement along with a nitride overhang and sidewall residue, a near zero bird's beak and full recessed oxide isolation have been achieved. This process has yielded MOS devices with a 1.5 μ mask feature size and is considered to be promising for submicron effective channel widths.

The implications of ion damage inherent in VLSI dry etching processes on the electrical properties of the metal-Si interface were reviewed by S. Ashok of the Pennsylvania State University. It was pointed out that the ion energy and dose thresholds for significant modification of the metal-Si (Schottky) barrier were as low as 50 eV and 5×10^{11} cm^{-2} respectively. The ubiquity of ion bombardment modification of the Si surface was established with recent experimental results, and the use of atomic hydrogen in passivating the damage at room temperature was also outlined. The role of atomic hydrogen in crystalline Si, however, is quite complex and a good amount of work is in progress to understand a variety of interesting phenomena with potential applications in VLSI.

M.-K. Lee and K.-Z. Chang of ITRI, Hsinchu, Taiwan, described a process for fabricating 2 μ-length poly Si, high-value resistors with semi-insulating characteristics. By using a capped high-temperature n-p neutralization step, they have been able to achieve sheet resistivities exceeding 10^8 ohms per square, but with a much reduced temperature coefficient of resistance relative to conventional poly Si (0.31 eV activation energy, as against 0.5--0.6 eV for the latter).

- Contact Metallurgy

A zirconium silicide contact metallurgy developed at the Fujitsu Laboratories, Atsugi, Japan, was described by M. Muto *et al.* He states that $ZrSi_2$, formed by

annealing at 650 C, has been found to reduce any interfacial SiO_2 and thus ensure an intimate contact with Si. The lateral growth of $ZrSi_2$ also occurs more slowly and uniformly relative to $MoSi_2$, thus offering significant advantages in submicron LSI. Another application of refractory metal silicides was offered by F.-C. Shone *et al.* of the Integrated Circuits Laboratory, Stanford University, as they implanted As and B into WSi_2 films and subsequently processed the wafers at high temperature to form simultaneously p-n junctions and ohmic contacts. Extremely shallow (0.1 μ) junctions have been obtained with peak surface concentrations of 4×10^{20} and 6×10^{19} cm^{-3} respectively for As and B. Application of the new method to device fabrication has also been demonstrated through fabrication of source and drain regions in p-channel MOSFETs, and models developed to characterize the diffusion/segregation of dopants in the silicide/silicon structure.

An alternative technique for simultaneous silicide ohmic contact and shallow junction formation was proposed by D. L. Kwong of the University of Notre Dame with the use of ion-beam mixing and rapid thermal anneal (RTA). Diode reverse leakage current density of the order of $10^{-7}A/cm^2$ was reported for p^+-n junctions formed by BF_2 implantation through $MoSi_2$ and RTA at 1100°C for 1 s. The silicide sheet resistance is less than 10 ohms per square for 180 keV As implanted through 200 A of Mo after 1100°C, 1 s RTA.

D. S. Gardner *et al.* of Stanford University reported on an interesting approach to stable VLSI multilevel interconnect metallization with the use of layered structures and homogeneous alloy films synthesized by sputter deposition. They showed that Al alloyed with Si and Ti and Al/Si layered with Ti reduced hillock formation in the films, and that the latter scheme also yielded resistivity comparable to that of standard metallization alloys. Unlike the case of Al/Cu alloy metallization, the Ti-based multilayer metallization is easily dry etched with no post etch corrosion or precipitation.

- Devices

The device design issues for deep submicron VLSI were addressed by P. Chatterjee of Texas Instruments in a comprehensive invited talk. He stressed the need to go below the current standard of the 5 V power supply, and pointed out that the new industry standard of 3.3 V would probably gain adoption only below 0.7 μ geometry. He discussed the performance limitations due to voltage nonscaling including the dependence of threshold voltage on channel length due to 2D effects, effective mobility reduction due to a vertical electric field, sheet resistance increase at shallow junction depths and increased subthreshold conduction in small geometry MOSFETs. Other issues of concern are reliability problems associated with hot carrier injection into the oxide, low-level impact ionization and time dependent breakdown of thin dielectrics, latchup problem in CMOS, isolation scaling problems and the interconnect bottleneck. Continued growth in the field is expected with evolutions in 3D integration and new ideas in device design and architecture.

The next paper in this session, by P. Yang and S. Aur of Texas Instruments, discussed a model for device lifetime due to hot carrier effects. Normalized substrate current (with respect to width) has been used as the controlling variable in this model of prediction of device lifetime. The succeeding paper by B. J. Sheu *et al.* of the University of California, Berkeley, provided a model configuration for high-speed/high-frequency circuit simulation. A feature of this approach is the use of multiple section lumped models to obtain accurate simulation with reasonable execution time.

C. T. Chuang and L. F. Wagner of the IBM Watson Research Center provided a very

comprehensive model for scaled down Schottky diodes, fully delineating the effect of minority carrier injection and charge storage. A floating guard ring is used in the experimental device structure to access internal nodes for measuring the separation between hole quasi Fermi and metal Fermi levels at large forward bias, thereby helping to develop a detailed equivalent circuit model. Highly doped shallow epi layers and high recombination velocity at the epi-substrate interface are required to achieve short storage times, and the model further offers a more optimistic projection on scaling of Schottky diodes.

M.-J. Tung and C.-Yu. Wu of the National Chiao Tung University, Hsinchu, Taiwan, described a general structure-oriented model to determine the substrate spreading resistance determining the CMOS latchup path and thus calculate the trigger current and holding voltage/current for comparison with measured values. J. S. Fu *et al.* of Sandia National Laboratory, Albuquerque, discussed transient 2D simulation of the physics of cosmic ion strikes on the sensitive junction of a CMOS static-RAM. The charge required for upset under such single-event phenomena has been calculated for both n- and p-channel devices under different bias conditions.

The final paper of this session, by C. S. Oh *et al.* from the Korea Advanced Institute of Science and Technology (KAIST), Seoul, described a p-channel Schottky-clamped MOSFET for use in CMOS VLSI. By using PtSi Schottky diodes shunted by small p-n diodes for the source and drain junctions, this device is intended for eliminating CMOS latchup while avoiding degradation of transconductance in the conventional Schottky MOSFET.

- Thin Dielectrics and Material

The first paper in this session was presented by M. M. Moslehi *et al.* of Stanford University and it dealt with direct nitridation of Si in a microwave plasma at low (less than 500°C) temperatures. Ellipsometric and RBS data were presented to characterize the films and impressive electrical and interfacial characteristics were also presented for films ranging in thickness from 30 to 1900 A. M. Young and W. G. Oldham of the University of California, Berkeley, on the other hand, presented results on plasma-enhanced nitridation of SiO_2. They showed that by optimizing the RF power and plasma temperature, one could obtain low-temperature oxynitride with acceptable electrical characteristics. A trade-off was also reported between nitridation efficiency and film quality.

A detailed model of dual dielectric MIS structures was reported by L. S. Yau and S. O. Chen of Intel Corporation, Aloha, OR, and it was shown that the inherent barrier asymmetry can be used to improve on parameters such as leakage current, maximum capacitance, and dielectric wearout resistance beyond the limits of SiO_2. S.-T. Chang *et al.* of Princeton University discussed charge trapping and impurity diffusion in nitrided oxides on Si. Their results obtained from SIMS show that thermally nitrided (in ammonia or N_2) oxide is a better barrier to boron diffusion than pure oxide. However, high electron trapping has been observed during avalanche injection of electrons into the dielectric. It is suggested that the beneficial effects of Si/SiO_2 interface can be retained along with the features of nitrided oxide by keeping the nitrogen away from the above interface. A potential application for nitrided oxides is in radiation-hardened MOSFETs, where the improved radiation resistance may be due to efficient electron-hole recombination through deep levels and trapped charge compensation in the insulating layer.

H. H. Tsai *et al.* of the National Chiao Tung University, Hsinchu, Taiwan, presented

their model on the growth kinetics of Si thermal oxidation with emphasis on accurately describing the initial oxide, the high initial growth rate and the decay in the growth rate. Based on comparisons with experimental oxidation data, a number of growth parameters have been deduced and compared with the results of Deal-Grove's simple linear-parabolic model.

The results of a study of wearout of thin gate and tunneling oxides were reported by I. C. Chen *et al.* of the University of California, Berkeley. Trapped holes in localized spots near the cathode interface were traced to be the cause of breakdown and a positive feedback mechanism was stipulated to explain the breakdown. A quantitative breakdown model resulting from this picture predicts a linear dependence of the log of time to breakdown on an inverse oxide electric field.

The final paper, by C. Y. Chang *et al.* of the National Cheng Kung University, Tainan, Taiwan, reported on an experimental study of GaAs bulk barrier transistor.

There were no organized talk sessions held at this meeting, but it was well thought enough out to allow adequate time for interaction among the participants. A postconference tour of the Hsinchu science-based industrial park was arranged for all interested participants, and it provided an excellent opportunity to observe firsthand the inroads made by Taiwan in VLSI and other specific high-technology areas. It is likely that this conference will continue biannually in the future preceding the Japanese VLSI symposia, and should attract an even wider international audience than in the past.

ULTRAFINE PARTICLES AND MAGNETISM IN JAPAN AND OBSERVATIONS ON MAGNETISM RESEARCH IN CHINA

C. D. Graham, Jr.

INTRODUCTION

The production of very small particles of metals and oxides, and the investigation of their physical properties, has been a popular subject in Japan for a number of years. The Japanese like to call such particles "ultrafine particles," and the upper size limit for ultrafine particles has been arbitrarily set at 1 μm diameter. Particles in this size range can be made by a wide variety of methods, including chemical reactions in the liquid or vapor phase, electrochemical techniques, and physical methods. Mechanical grinding does not generally produce such small particles, but condensation of metal vapors in a low pressure inert-gas atmosphere is often effective. The metal vapor can be created by induction or resistance heating, by a plasma jet, or by an electric arc, and sizes down to about 100 Å diameter can be produced.

ULTRAFINE PARTICLES

Since 1981, the Ministry of Science and Technology (MST) has supported a substantial five-year research project on ultrafine particles. The project leader is C. Hayashi, a remarkable man who is president of a substantial number of companies but remains active in research. The industrial group is Ulvac, a major manufacturer of vacuum equipment for industrial and laboratory use. One of the Ulvac companies is Vacuum Metallurgical Corporation, a producer of superconducting materials and of superconducting magnets. I visited two groups of the "Hayashi project," one at the Ulvac plant outside Tokyo, and one at Meijo University in Nagoya.

- Meijo University

The work at Meijo is quite remarkable. Meijo is a large private university, not noted for research; the fine-particle work is done there because Professor R. Uyeda, formerly of Nagoya University and a long-time worker in fine particles, moved to Meijo after his retirement from Nagoya. He arranged for the creation of an electron microscope research group centered around Dr. S. Iijima, who returned to Japan after 12 years at Arizona State University. Iijima received the first production model of a new transmission electron microscope made by a company known in the U.S. as ISI, and has fitted it with an array of oil-free turbopumps as well as an elaborate system for producing ultrafine particles and introducing them directly into the microscope. The particles are made by arc melting, and are conducted into the microscope column in a stream of inert gas whose pressure is reduced in several stages. The particles enter the microscope at velocities of the order of 100 m per sec, and spaced apart so that they arrive on the sample holder grid more or less one at a time. On their way, the particles can be melted or partially coated with another element.

The most spectacular results have been obtained using Si particles which are slightly oxidized and then exposed to Au vapor. This produces Au particles near 25 Å diameter on an insulating substrate. In the microscope, one sees a lattice image of the Au particle. Furthermore, the effective intensity of the electron illuminations is such that exposure

times of 1/60 of a second are possible, rather than the usual 2 or 3 seconds. The images are recorded using a high quality videotape system.

The surprising result is that the Au particles appear to be in constant motion. Not only do they change their exterior shape, but their crystal orientation changes, showing various degrees of twinning. The effect is like the squirming of a single-cell organism, and in the publicity releases fairly widely distributed in Japan, the Au particles were called "living" particles. The particle motion is apparently driven by electrostatic forces rather than thermal energy; if the Au particles are on a conducting carbon substrate, the motion ceases. The microscope, although delivering a high level of electron illumination, is not especially high in accelerating voltage, only 120 kV.

More surprising to me was the observation that at the intersection of several planar exterior surfaces, the Au atoms continually leave and rejoin the surface. The appearance is like a pool of boiling lava. The astonishing point is that atoms rise from the surface by three or four times their own diameter, but always return. This implies a long-range attractive force whose origin is unclear. Iijima is an experimentalist; he suggests that there may be a contamination layer of light elements that somehow holds the Au atoms near the surface.

Iijima's videotapes have been shown at a meeting of the Physical Society of Japan, and also at a small meeting at Arizona State University, but I think they deserve to be better known. (I have a copy of the tape, 3/4" size, which can be borrowed.) The experimental set-up that made the work possible is highly impressive: a new, high-quality microscope dedicated to a single research project and backed by a large budget.

- Ulvac

At the Ulvac plant, I saw research on improved production methods for fine particles. The principal worker there is M. Oda, and his favored production method is induction melting. He has developed a scheme for inserting heated (or cooled) fine stainless steel tubes into the region where the metal vapor is condensing, to extract samples of varying particle size and size distribution. Sizes well below 1000 Å can be obtained, with reasonably narrow-size distribution. The particles are nearly spherical in shape, but magnetic materials show a strong tendency to form long chains of particles (Oda calls them "necklaces").

Recent effort has centered on mixing two kinds of powders in a single gas stream, and letting the stream impact a rigid (usually metallic) surface. The particles generally adhere well, so this is a method for building up surface coatings or even bulk materials of metastable compositions. Iron-silver coatings that are homogeneous at the limit of resolution of a scanning electron microscope have been produced.

Ulvac is the principal (perhaps the only) supplier of Fe-Co particles used to make "metal" recording tapes. This tape was developed mainly by the Fuji Film Company, and is now widely available. It is measurably better than conventional oxide tapes, but requires changes in the drive circuits of the recording head of the recorder. I saw the production equipment at Ulvac, which consists of two evaporation and condensing towers, each perhaps 3.5 m diameter and two stories high, equipped with massive dc coils to apply a field of 500 in to the condensing particles. (This causes the "necklaces" to grow in an array of approximately parallel lines, thus improving the magnetic properties.)

Production is at the rate of several tons of powder per month, although metal tape has not proved very popular with the public. The improved properties apparently are not thought to be impressive enough to justify the extra cost.

This metal tape is used for audio recording; it is not to be confused with another kind of metal tape under development for perpendicular recording of digital information. The latter kind uses a continuous metal layer on a polymer film rather than metal particles.

The ultrafine particles of almost any size develop a surface oxide layer that largely protects them from further reaction, so the particles are remarkably stable at room temperature. They can be partly or completely oxidized to produce oxide particles. The principal commercial use to date is in recording tape; the Ulvac people hope that some oxide or other ceramic particles may be useful in making high density pressed and sintered objects. Sintering is greatly accelerated by the use of very small particles.

MAGNETISM LABORATORIES IN JAPAN

- Sumitomo Metal Mining Company (SMM)

This firm is not to be confused with Sumitomo Special Metals Company, developers of the super permanent magnet "Neomax" ($Fe_{14}Nd_2B$). Although descended from a common ancestor, the two companies do not cooperate. When I asked about the relationship, I was told, "We are not enemies." SMM is primarily a smelting company, and is a major supplier of Cu, Ni, Co, Ag, Au, Pb, Zn, and rare-earths. It no longer conducts mining operations, with the dazzling exception of a rich new gold mine just opened in Japan. The profits from this mine are to finance a major 15-year research program to broaden the company's product line. The aim is to build on current materials expertise by developing more sophisticated materials (optical, semiconducting, magnetic), and to go onward to device production where there is a reasonable chance to make a profit.

Current work in magnet materials is centered on two major products: bonded rare-earth magnets and magneto-optical recording disks. Conventional wisdom is that 2-17 type rare-earth materials are best to use for bonded magnets (magnet powders embedded in a polymer matrix), since 2-17 materials are less sensitive to the surface condition of the particles than 1-5 type compounds. SMM has developed a surface treatment for $SmCo_5$ powder, using a silane compound, that largely overcomes the surface degradation problem when $SmCo_5$ is mixed with nylon. By carrying out the magnetic alignment step at 260°C, where the viscosity of nylon is relatively low, very good magnetic properties are obtained: over 11 MGOe energy product. The use of nylon, a thermoplastic material, allows recycling of scrap, further lowering production costs. SMM is planning a new plant to produce bonded magnets using this process.

I asked why SMM, a midget in the electronics world, felt it could compete with giants like Matsushita and Hitachi in magneto-optic recording. The answer was in three parts:

- SMM is a producer of rare-earth materials, and will have a price advantage if rare-earth materials are used for magneto-optic recording (which is likely),

- SMM has experience and expertise in the uniform sputter coating of large areas, and therefore hopes an 8" disk will be the standard, not 5" or 3", and

- the potential business is large, so that a small market share can still be profitable.

The manager of the magnetics group, and vice-director of the research center, is H. Satoh, until five years ago a full-time research worker at the government Electrotechnical Laboratory. He seems to be an effective manager, and clearly enjoys the work. Because of SMM's history and image as a smelting company, he finds it difficult to hire top-level students from the "best" universities. Consequently, he has adopted the strategy of looking for the number one students at smaller schools, assuming that a statistical distribution will place a few first-rate people in second-rank universities. Satoh spent a year at Colorado State University, and regularly attends international meetings. I expect that his laboratory will become better known in the magnetics community.

- Tohoku Metals

Tohoku Metals is an old and somewhat conservative firm. Since I visited the plant over 20 years ago, the company has expanded substantially, and has much improved the old buildings. It has also polished its image by calling itself "Tokin," an abbreviation of the Japanese pronunciation of its formal name. Tokin is a producer of special alloys and materials, including all types of magnetic materials: hard and soft ferrites, permalloy, Sendust, Alnico, and rare-earth magnets (but not silicon steel). As is the case with materials companies all over the world, Tokin is producing components and devices in addition to materials, and now half its revenue is from this class of sales: power supplies, electric noise simulators, shielded rooms, etc.

Tokin is, of course, developing FeNdB type permanent magnets, and has reached an energy product greater than 40 MGOe. This work is done in cooperation with the group of Professor Honma at the Research Institute for Iron, Steel and Other Materials at Tohoku University; it is not clear to me how the work and the research equipment are divided. My impression is that Tokin does relatively little research on new materials in its own laboratories, but tries to take advantage of developments in Japanese universities, especially at nearby Tohoku University. For example, Tokin says it is the sole producer of the static induction transistor (SIT), invented or developed by Professor Nishikawa. This is a fast acting high-voltage device which Tokin uses in a line of induction heating power supplies.

The most impressive production equipment was a pair of big hot isostatic pressing (HIP) units, each with a working space about 30 cm in diameter and 1.5 m high, using Ar gas as the working fluid. These are used to produce high-density ferrites and Sendust products. I also saw a big vacuum-induction melting apparatus equipped with vacuum air locks, used for large-scale production of permalloy and Sendust ingots. The ingot size was about 100 kg.

- Department of Electrical Engineering, Tohoku University

Professor T. Wakiyama heads the magnetic materials work in this department, but his main research effort is in searching for metastable or layered structures with high superconducting transition temperatures. Most of the magnetics work is now done by Migaki Takahashi, son of the recently retired Minoru Takahashi of the applied physics department of Tohoku, with Wakiyama acting as a general supervisor and sponsor.

Various ramifications of the hcp $\leftrightarrow$ dhcp phase transition in Co + 1 to 1.5% Fe, first discovered by Wakiyama, have been investigated. It is now clearly established that the phase transition can be driven by a magnetic field applied in the appropriate crystallographic direction, at least over a temperature range near room temperature. Since both

phases have nearly the same magnetization, the energy difference must come from the crystal anisotropy. An extensive study has been made of the effects of ordering on the magnetic properties of FeAlSi single crystals near the composition of Sendust. This alloy, developed in Sendai about 50 years ago, is still widely used for tape recorder heads. It is made and heat-treated according to time-tested recipes, but the exact relation between the structure, composition, and magnetic properties remains somewhat obscure.

New equipment is being constructed for the preparation of multilayer films and magneto-optic materials. This group is not very well supported financially, and much of the equipment is made in-house.

- Research Institute for Electrical Communications, Tohoku University

The former main campus of Tohoku University, located near the downtown area of Sendai, was largely abandoned by undergraduate students when several new campuses were built in the 1960s and 1970s. Now the old campus is occupied by a group of seven or eight research institutes, mostly housed in fairly decrepit old buildings. There are also some abandoned buildings, including the former university library, giving the area a rather forlorn appearance. The largest institute is the Research Institute for Iron, Steel and Other Metals, but materials work is also carried out in some of the other institutes, such as the Institute for Metallurgy and Mineral Dressing, and the Institute for Electrical Communications. The actual work of Japanese institutions is not always reflected in their official names; one of the groups in the Institute for Electrical Communications is in fact working on the production and properties of 6% silicon-iron. This material is in some ways superior to conventional 3% Si-Fe, notably in having nearly zero magnetostriction and higher electrical resistivity. This group was led for many years by Professor N. Tsuya, who has recently retired. No successor has been named but the work is continuing under Associate Professor K. Arai and assistant K. Ohmori.

The 6% Si-Fe alloy cannot be made by conventional metallurgical methods because of its brittleness; it can, however, be made in thin sheet form by rapid solidification processing. The Tohoku group uses mainly a two-roller method with stainless steel or FeCr alloy rolls. (The choice of roll material remains part of the black art of rapid solidification technology.) The two-roller method gives good surface quality on both sides and allows the production of somewhat thicker sheets than the single roll method. The thickness limit is set by the appearance of an equiaxed or dentritic grain layer along the midplane of the sheet, separating two columnar layers produced by directional solidification from the surface.

The work of this group is generally published fairly promptly, and there seemed to be nothing very new in the current results. The real interest in this subject is whether one or more steel companies will make a serious effort to produce and market 6% Si-Fe to compete with conventional 3% Si-Fe and/or amorphous alloys. The steel companies are not revealing their intentions. The Tohoku group has also made Sendust by rapid solidification, and has examined the effect of ordering on the magnetic properties of Fe-Si single crystal.

I did see a very interesting measurement technique used to control the shape of the output voltage wave form in magnetic testing of small cores. Usually one wants the wave-form to be sinusoidal, and since the magnetization *vs.* field curve is both nonlinear and hysteretic, the wave form of the drive field or current is highly distorted. The usual control method measures the difference between the actual output voltage and a pure sine wave, and uses this error signal in a feedback control circuit. There are some limitations

to this method, especially when the sample size is small. Arai and Ohmori synthesize a complex wave shape for the drive current, using a digitally-controlled frequency generator. The drive current wave form is adjusted until the output wave form is sinusoidal; this avoids the use of feedback circuitry. The frequency and phase components for a given sample size, induction level, and fundamental frequency are stored in a small computer, and generally need only minor adjustments from sample to sample. The method is in regular use, and seems to be satisfactory.

- Kyoto University

Professor Yoji Nakamura is a senior faculty member in the metals science department at Kyoto University. He has worked for many years on the magnetic properties of intermetallic compounds and alloys, with a special interest in Invar materials. His approach to these problems falls between solid state physics and classical metallurgy. The laboratories are typical of those in old Japanese universities--drab and dingy with old equipment. However, results are being produced at a brisk rate. Nakamura and his younger colleague, K. Sumiyama, are using the sputtering technique to investigate the properties of metastable phases, mostly crystalline. In this sense, he is following the path opened by Pol Duwez at Cal Tech when he invented the splat quenching technique. Sputtering, however, permits the production of solid solutions of systems that are immiscible in the liquid state, such as silver-iron.

Much of our discussion was on the relative merits of sputtering *vs.* other production methods, and of the various kinds of sputtering systems that are available. There is widespread difference of opinion on these points, and we did not resolve the problem.

- Hitachi Central Research Laboratory (Kokubunji, near Tokyo)

Magnetics research at Hitachi, as might be expected, centers on magnetic recording and magnetic memory devices. Conventional parallel recording, perpendicular recording, magneto-optic recording and bubble memories are all under development. Hitachi has had a working prototype magneto-optical recording system since 1983, and is planning to be in production within two years. They use a TbFeCo recording material, and have concluded that a rewritable magneto-optical disk is not practical; one track must be erased completely and then rewritten. The reason is that the field required for erasing is large, and cannot be switched fast enough to erase one bit at a time. The software designers apparently can handle the problem of erasing a track before re-recording.

The recording properties of CoCr (for perpendicular recording) have been substantially improved by precoating the polymer substrate with 300 Å of amorphous Ge. For reasons that are not obvious, this causes the CoCr to nucleate and grow immediately in a well-aligned columnar c-axis structure. Without the Ge layer, a random structure nucleates and gradually converts to an aligned structure as growth proceeds. About 25 precoating materials were examined before Ge was selected; crystalline Ti was next best.

Both perpendicular recording and magneto-optical recording, which are not yet available in commercial systems, will need to have standards set for disk size, track spacing, switching conditions, etc., if the disks are to be interchangeable between systems. Committees in Japan are starting to work on these problems, but apparently they are not near agreement.

Hitachi is one of three makers of bubble memories in Japan (there are two in the

U.S.). The current product is a 1 MB unit, and with materials now developed they see the prospect of 16 MB units. That seems to be the limit, unless a magnetic material can be found to replace garnet as the storage medium.

In bubble memories especially, and to some extent in magneto-optics, the Hitachi people seemed a little saddened by the fact that they no longer feel much competitive pressure from the U.S. In bubble memories, they clearly feel that they are leading the world. In magneto-optics, they noted that 30 to 40 Japanese firms (major computer makers, consumer electronics makers, optical products producers, and chemical companies) are in the race to develop devices. In the U.S., they only knew of four competitors. Of course, two of them are IBM and 3M--hardly lightweights--but still, the difference between the U.S. and Japan is large. I noted something of the same attitude at Sony; discussing the problem of increasing U.S. exports to Japan, a Sony man rather undiplomatically remarked, "I don't know what is available in American that we would want to import--maybe some software, or cheap rice."

The visit to Hitachi was arranged by Dr. S. Takayama, former graduate student and postdoctoral fellow at the University of Pennsylvania, who was also my principal host along with Y. Sugita, who is in charge of magnetic materials work.

- Research Development Corporation of Japan (JRDC)

Normally a private company, this organization is financed and controlled by the Ministry of Science and Technology. Its stated aim is to support exploratory research in selected areas, trying to change the pattern by which Japan exploits the scientific discoveries of other countries but seldom creates new discoveries of its own. About eight projects are supported at any one time, each for a period of five years. The system has been in operation since 1981, so the first projects will end in 1986. Each project has 30 to 50 full-time workers, usually subdivided into four or five subgroups, often at different locations, with an annual budget of about $5 million. A project is organized and led by one person, usually a university professor, but sometimes an industrial scientist. JRDC is under the Ministry of Science and Technology, and the national universities are under the Ministry of Education, some bending of the rules is required for faculty from national universities to participate in this program. In some cases this has been done, but most of the academic participants are from private universities. The working scientists are mostly from companies with an interest in the subject matter of the project. They are paid by JRDC, but expect to return to their companies. This system has the advantage of providing an experienced and capable research staff, also to produce results quickly without extensive training. It also has some drawbacks. If the worker's parent company takes a strong interest in the project, conflicts can arise between the project leader and the company management over the direction of the program; the worker is then in the uncomfortable position of receiving conflicting instructions from two bosses. Sometimes the workers are recalled to their companies on short notice. And in my experience, the workers tend to have the company viewpoint of looking for relatively short-range practical results, not radically new ideas. Because they must be physically separated from the national universities, the groups also tend to be too much isolated from the best and most original Japanese scientists. They do have money for excellent new equipment, and they do produce a lot ot useful information. Communication between the subgroups is generally good, with fairly frequent visits back and forth, and an annual review meeting for all the participants.

Current projects include new amorphous materials, ultrafine particles (described in

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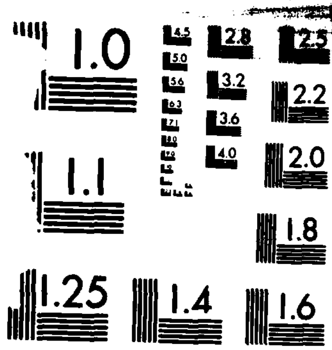

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

part elsewhere in this article), semiconductor materials, special polymers, and a number of programs in biology. One of these is called the "superbug" project; it is identifying and trying to exploit organisms that can live under extreme conditions of temperature, pressure, acidity, etc.

An interesting and apparently unresolved question is what happens to the equipment (sometimes extensive) purchased by JRDC when the projects end after five years. The university people are naturally appalled by the idea that their lovely new equipment might be taken away. The only clear rule seems to be that it cannot be given to a national university; that would involve a transfer of assets from one ministry to another. The Japanese government is not always an ideally functioning monolithic integrated organization, as it is sometimes pictured in the popular management journals.

OBSERVATIONS ON MAGNETISM RESEARCH IN CHINA

A week of technical visits in Beijing and Shenyang led me to conclude that Chinese laboratories are rapidly upgrading their facilities and improving their experimental skills, but that relatively little new science or technology is yet emerging. I found that two laboratories (Central Iron and Steel Research Institute, Beijing, and Northeast University of Technology, Shenyang) have produced FeNdB type magnets with energy products near or above 40 MGOe, demonstrating that the Chinese magneticians can promptly reproduce results reported in the West.

One bit of magnetic metallurgy was new to me, and could be important: an iron or iron-silicon alloy containing sufficient carbon to be in the austenite phase can be converted to ferrite (bcc) by decarburization at constant temperature (in an appropriate temperature range). Under certain conditions, not difficult to attain, the ferrite grains grow in a columnar structure, inward from the sheet surface, and with a <100> growth axis. The growth can be rapid, proceeding to the center of a thin sheet in a few minutes at 850°C. This appears to give a practical method of producing a sheet with a random (001) planar texture, which should be just right for punching motor laminations.

I was told about this by Luo Yang of the Central Research Institute for Iron and Steel (Beijing), who struck me as a very capable man. He also explained that his laboratory and others like it, no longer operate on direct government support; he must arrange much of his own financing through research contracts with production units such as steel plants.

U.S.). The current product is a 1 MB unit, and with materials now developed they see the prospect of 16 MB units. That seems to be the limit, unless a magnetic material can be found to replace garnet as the storage medium.

In bubble memories especially, and to some extent in magneto-optics, the Hitachi people seemed a little saddened by the fact that they no longer feel much competitive pressure from the U.S. In bubble memories, they clearly feel that they are leading the world. In magneto-optics, they noted that 30 to 40 Japanese firms (major computer makers, consumer electronics makers, optical products producers, and chemical companies) are in the race to develop devices. In the U.S., they only knew of four competitors. Of course, two of them are IBM and 3M--hardly lightweights--but still, the difference between the U.S. and Japan is large. I noted something of the same attitude at Sony; discussing the problem of increasing U.S. exports to Japan, a Sony man rather undiplomatically remarked, "I don't know what is available in American that we would want to import--maybe some software, or cheap rice."

The visit to Hitachi was arranged by Dr. S. Takayama, former graduate student and postdoctoral fellow at the University of Pennsylvania, who was also my principal host along with Y. Sugita, who is in charge of magnetic materials work.

- Research Development Corporation of Japan (JRDC)

Normally a private company, this organization is financed and controlled by the Ministry of Science and Technology. Its stated aim is to support exploratory research in selected areas, trying to change the pattern by which Japan exploits the scientific discoveries of other countries but seldom creates new discoveries of its own. About eight projects are supported at any one time, each for a period of five years. The system has been in operation since 1981, so the first projects will end in 1986. Each project has 30 to 50 full-time workers, usually subdivided into four or five subgroups, often at different locations, with an annual budget of about $5 million. A project is organized and led by one person, usually a university professor, but sometimes an industrial scientist. JRDC is under the Ministry of Science and Technology, and the national universities are under the Ministry of Education, some bending of the rules is required for faculty from national universities to participate in this program. In some cases this has been done, but most of the academic participants are from private universities. The working scientists are mostly from companies with an interest in the subject matter of the project. They are paid by JRDC, but expect to return to their companies. This system has the advantage of providing an experienced and capable research staff, also to produce results quickly without extensive training. It also has some drawbacks. If the worker's parent company takes a strong interest in the project, conflicts can arise between the project leader and the company management over the direction of the program; the worker is then in the uncomfortable position of receiving conflicting instructions from two bosses. Sometimes the workers are recalled to their companies on short notice. And in my experience, the workers tend to have the company viewpoint of looking for relatively short-range practical results, not radically new ideas. Because they must be physically separated from the national universities, the groups also tend to be too much isolated from the best and most original Japanese scientists. They do have money for excellent new equipment, and they do produce a lot ot useful information. Communication between the subgroups is generally good, with fairly frequent visits back and forth, and an annual review meeting for all the participants.

Current projects include new amorphous materials, ultrafine particles (described in

BIOTECHNOLOGY IN JAPAN

Herman W. Lewis

SURVEY OF APPLICATIONS

In a previous issue of the *Scientific Bulletin* [*10* (2), 11 (1985)], the organization of the biotechnology enterprise in Japan and its infrastructure was presented. This second part surveys the applications as of early 1984. The research and development described in this section, while not a comprehensive survey, is a useful sampling of Japanese biotechnology activity. Some of the information was obtained directly from researchers during visits to their laboratories, some of it indirectly in conversation with third party researchers and some of it from English-language newspaper and journal accounts. Two relevant symposia, one in English and the other with English summaries, were useful sources of information: the International Meeting on Chemical Sensors held in Fukuoka in September 1983 and the First Symposium on Biotechnology R&D sponsored by the Research Association for Biotechnology held in Tokyo, December 1983. The presentations of the latter meeting have been summarized in an earlier section.

To date, no products generated in Japan by modern biotechniques have reached the marketplace, but a number of drugs are in the clinical testing stage and should be marketable within the next few years. Since most of the biotechnology activity in Japan to date is identical to or derivative of similar activity in the U.S., it is not especially useful, in most cases to describe technical aspects in detail. In some cases, bullet statements or lists are sufficient to provide a picture of the scope of the Japanese activity. Research projects that were in the early stages of development during the author's visit to Japan are not included.

- DRUGS, VACCINES, ANTIBODIES

As in the U.S., the earliest applications of the new biotechniques were in the production of medically related products. This is partially due to the fact that the same factors that influenced decisions in U.S. companies also influenced decisions in Japanese companies. Mostly, however, it is due to the heavy reliance of companies in Japan on companies in the U.S. for technology transfer. This is most readily seen in the production of interferon.

It was mentioned earlier in this report that Japanese companies were especially moved into action by the hyperbole in the U.S. media about interferon. Most of the companies that made the decision to produce interferon use recombinant DNA technology to synthesize the protein in microorganisms, but a few extract it from cultured human cells. Listed below are the companies that are well into clinical trials of the drug. The non-Japanese companies with which they are linked in a variety of types of agreement are shown in parenthesis.

. Alpha Interferon

Green Cross Corporation (Collaborative research)
Hayashibara Biochemical Laboratories
Nippon Kayaku Company, Ltd.
Nippon Roche K.K.
Otsuka Pharmaceutical Company

Sumitomo Chemical Company, Ltd.
Takeda Chemical Industries, Ltd. (Hoffman La Roche)
Toyo Jozo Company, Ltd.
Yamanouchi Pharmaceutical (Shering Plough)

- Beta Interferon

  Green Cross Corporation (Collaborative research)
  Kyowa Hakko Kogyo Company, Ltd.
  Meiji Seika Kaisha, Ltd. (G.D. Searle)
  Mitsui Toatsu Chemicals, Inc. (Genentech)
  Mochida Pharmaceutical Company, Ltd. (G.D. Searle)
  Otsuka Pharmaceutical Company
  Sumitomo Chemical Company, Ltd. (Welcome Company)
  Toray Industries, Inc. (Extracted from cell cultures)

- Gamma Interferon

  Daiichi Seiyaku Company (Genentech)
  Green Cross Corporation (Bristol-Myers)
  Kanegafuchi Chemical Industry
  Kyowa Hakko Kogyo Company, Ltd.
  Meiji Seika Kaisha, Ltd. (G.D. Searle)
  Shionogi Company, Ltd. (Biogen)
  Sunstar, Inc.
  Suntory, Ltd. (Shering Plough)
  Takeda Chemical Industries (Roche)
  Toray Industries, Inc. (Genentech)

- Monoclonal Antibodies:

The use of hybridomas to produce monoclonal antibodies is receiving extensive attention in Japanese companies for application as therapeutic agents, for diagnostic tests, and for separation and purification processing. The following monoclonal antibodies are well into the clinical testing stage.

As therapeutic agents:

monoclonal antibodies to thyroid disease,
monoclonal antibodies to tumor necrosis factor,
monoclonal antibodies to herpes simplex antigenic protein, and
monoclonal antibodies to tetanus.

For diagnostic testing:

monoclonal antibodies to detect glycohemoglobin (diabetes),
monoclonal antibodies to detect estrogen levels to measure placental function of pregnant mother and liver function of fetus, and
monoclonal antibodies to detect catecholamine (neuroblastoma and other nervous disorders).

For separation and purification:

monoclonal antibodies to alpha and beta interferon.

- Vaccines

Using recombinant DNA technology, researchers at Osaka University have developed a vaccine against the Chicken Pox virus.

Using recombinant DNA technology, researchers at Kyushu University have developed a vaccine against the Herpes simplex virus.

- Drugs, hormones, and biologicals

The following products, made in microorganisms using recombinant DNA technology, are in the clinical testing stages. Where the product was developed in an agreement arrangement with a foreign company, the latter is indicated in parenthesis.

Human growth hormone--produced and being tested for anti-infantilism by Sumitomo Chemical Company. (Kabi Company of Sweden)

Human insulin--produced and being tested on diabetes patients by Shionogi Company, Ltd. (Eli Lily)

Parathyroid hormone--cloned and produced by Toyo Jozo Company, Ltd.

Human interleukin 2--produced and tested for treatment of patients with immune deficiency diseases and for cancer immunotherapy by Ajinomoto Company.

Human interleukin 2--produced and being tested by Shionogi Company.

Human interleukin 2--produced and being tested by Takeda Chemical Industries.

Human calcitonin--has been cloned by researchers at Suntory. It is being tested to see if it is naturally amidated after administration.

Tumor Necrosis Factor (TNF)--has been produced and is being tested clinically as an anticancer drug. (Biogen)

Serum albumin--has been produced by Mitsubishi Chemical Industries.

Urokinase--produced and being tested as a thrombus dissolver by Mitsubishi Petrochemical Company (Abott Laboratories)

Urokinase--produced and tested by Asahi Chemical Industry Company.

Tissue Plasminogen Activator (TPA)--produced and being tested as a thrombus dissolver by Mitsubishi Kasei (Genentech)

Tissue Plasminogen Activator--being researched and tested at Kyowa Hakko Kogyo Company (Genentech)

- BIOREACTORS

A bioreactor is a facility that uses microbes, enzymes, or other cell components as catalysts for chemical reactions. The technology for developing these systems aims at achieving continuous reactions in compact facilities. Such reactions proceed at normal pressure and temperature and therefore do not consume large quantities of water or energy. This confers a great advantage to industrial processing compared to conventional ways of carrying out the same chemical reactions. Even in industries where production is based on fermentation methods, the development of bioreactors is a major advance in technology. In contrast to the conventional batch method in which the stock and the products are mixed by fermentation in a single tank, the new technology involves charging the stock from the top of a tank in which an immobilized enzyme, cell or part is packed, resulting in the product with higher efficiency. It is estimated that the use of bioreactors reduce production costs by 40% over conventional methods. The key to bioreactor technology is immobilization of enzymes which involves trapping the enzyme in a carrier and keeping it there insoluble in water and active for a long time. The most successful bioreactors in use are the systems using immobilized aminoacylase producing aspartic acid and phenylalanine and immobilized fumarase producing malic acid. Both industrial and academic laboratories are engaged in research to develop immobilized enzyme systems for specific products. The research of industrial laboratories is summarized in the earlier section of this report describing the Research Association for Biotechnology. The research of several university laboratories is summarized below.

- Enzyme Immobilization - Chemical engineers of Tokyo University (S. Furusaki and N. Asai) have developed a new technique for enzyme immobilization. It involves immobilizing enzymes on a porous polytetrafluoroethylene membrane with a nonporous polyurethane coat by the use of electrostatic force. The immobilized enzyme can be recovered by supplying a reversed electrical potential.

- Immobilized Yeast Producing Ethanol - Researchers of Tokyo University have been studying the reaction behavior of *Saccharomyces formosensis* immobilized by polyacrylamide when the yeast cells are resting and when they are growing. The reaction rates as expressed by the Michaelis-Menten equation with a linear ethanol inhibition factor are very close for both types of yeast cells, but considerably larger than that of *S. cerevisiae*. Distribution of the growing yeast cells inside the carrier gel shows that cell density is higher near the surface of the carrier.

- Continuous Cellulase Production - Researchers at Kyoto University have developed an apparatus for continuous cultivation using an internal separator of fungal cells. The cell-free medium is removed by filtration through nylon mesh. Using this apparatus, continuous cellulase production can be carried out using cellobiose as the carbon source and a cell holding culture of *Trichoderma reesei*. The cell holding culture makes it possible to retain a high density of mycelium while removing metabolic products. Continuous operation of the cell holding culture with constant feeding of fresh medium results in a large increase of cellulase and B-glucosidase activities. The proper amount of cellobiose supplied to induce cellulase while lowering the repressive effect of catabolite is approximately 8-12 mg/h/g of mycelia.

- Construction of Enzyme Conjugates - Researchers at Kyoto University have constructed enzyme-enzyme heteroconjugates of phosphoglyceromutase, enolase and pyruvate kinase which sequentially act to produce ATP in the glyolytic

pathway. Comparison of the reactions catalysed by the conjugates with that by a mixture of the free enzymes shows that the lag time required for the system to achieve a steady state was reduced in the conjugate system. The Km values and heat stability are the same in the immobilized conjugates and free enzymes.

- Prostaglandin Synthesis on Immobilized Microsomes - Prostaglandins are a class of pharmacologically active compounds derived from arachidomic acid. Researchers at Kyoto University have immobilized the prostaglandin synthetase enzyme complex in a stable, solid gel support through which reactants and products diffuse, making possible batch or continuous synthesis. A photocrosslinkable gel with lipophilic and hydrophilic properties entrap microsomes containing the prostaglandin synthetase. Ram seminal microsomes were used.

- Creatinine Assay Using an Immobilized Enzyme - Researchers at the Kyoto University Medical School have developed a method for automated analysis of creatinine in serum using immobilized enzymes in column form. The method is based on the determination on ammonia formed by the action of creatinine deiminase. Endogenous ammonia in serum is removed by immobilized glutamate dehydrogenase column prior to the action of creatinine deiminase. The method provides linearity of the data up to 0.10g of creatinine per liter. The immobilized enzyme reactor shows operational stability for a two-month period, during which time it can be used repeatedly (over 2000 times).

- Inorganic Phosphorus Assay Using Immobilized Enzyme - Researchers at the Kyoto University Medical School have developed a method for the automated analysis of inorganic phosphorus in serum. The method is based on the determination of hydrogen peroxide formed by the action of pyruvate oxidase on inorganic phosphate and pyruvate. When applied to the determination of inorganic phophorus in serum, the method shows linearity up to 0.20g inorganic phosphorus per liter.

- BIOELECTRONICS

Under the topic of bioelectronics are described those applications of research that involve the use of the properties of life as detectors (i.e., biosensors) coupled with electronics to measure the reactions sensed. At this early stage the major interest in this application is in laboratories concerned with extending medical electronics (i.e., the development of blood glucose sensors, uric acid sensors, amylase sensors, etc.).

- Electron Transfer by Immobilized Cyanobacteria - Researchers in the applied biochemistry department of Shimane University have demonstrated that intact *Phormidium sp.* cells immobilized on a SnO_2 semiconductor electrode can transfer electrons to SnO_2 in a light-dependent reaction. Drying a "wet" algal electrode at 50°C for 60 minutes increases the photocurrent output capacity by 100-fold. The magnitude of the photocurrent increases with increasing light intensity and depends on the nature of the electrolyte solution. The photocurrent action spectrum peak coincides with the absorption peak of the light-harvesting pigment, phycocyanin.

- Biosensor Using Chemiluminescence - Professor Murachi of Kyoto University has developed a continuous flow reactor that can analyze glucose, uric acid, cholesterol, free fatty acids and other blood chemicals. It is a fixed enzyme column-type reactor. An oxidized enzyme that generates H_2O_2 is fastened to the surface of glass beads. The fixed enzyme is stable enough to be used at least 2000

times. The proton is obtained through the chemiluminescence of generated H_2O_2 by using luminol and potassium ferricyanide. The chemiluminescence process is 100-1000 times more sensitive as the colorimetric process normally used, and requires one-tenth to one-twentieth of the quantity of specimen as used in conventional testing. Very small quantities of blood can be used. The device uses a microcomputer for automated liquid feed, measurement, and data processing. It can perform 240 tests per hour.

- Development of Device for Transmitting Chemical Information - Dr. M. Aizawa, of Tsukuba University, has developed a device for transmitting chemical information using a nerve synapse as a model. In presynaptic membranes, neurotransmitters are sealed in vesicles. In Dr. Aizawa's device, he entrapped acetylcholine in a thin layer of graphite. Acetylcholine has a positive charge in a neutral solution and he found that when the graphite is electrochmically reduced in the presence of acetylcholine, the acetylcholine is inserted in the reduced graphite. Conversely, when the graphite is returned to the neutral state by electrochemical oxidation, the inserted acetylcholine is released. He was also able to get this insertion and release of acetylcholine by controlling the potential of a fabricated polyacetylene membrane. In similar fashion, using a polypyrrole membrane, he was able to get the insertion and release of glutamic acid by controlling the potential of the membrane. Dr. Aizawa is currently refining the design of his device to extend the application of controlled molecule capture and release by electrical stimuli as an interface between living and nonliving systems. This research is in a very early stage.

- Diabetes Detector - The Matsushita Electric Industrial Company (Osaka) has developed a sensitive device to detect and quantify glucose and it plans to commercialize it as a diabetes detector. Glucose in biological fluids is measured by adding a gluteraldehyde and a special electrode which contains fixed glucose oxidase. The enzyme catalyzes the oxidation of glucose by the gluteraldehyde. The electron transfer during the oxidation is measured by a specially developed electrode made from thin films of carbon, polycarbonate resin, and platinum. The company believes that the diabetes diagnostic device it plans to develop will reduce testing time by at least 50% compared to conventional diagnostic devices.

- Enzyme Sensor to Measure Glucose - Researchers at the Mitsubishi Electric Company have developed a sensor for measuring glucose level of solutions using the enzyme glucose oxidase immobilized on a thin film. Besides the film the sensor consists of a transistor and an electrode sensitive to pH. The film containing the enzyme is a few microns thick and is attached with water soluble, optically solidifying resin and glutaraldehyde. When the sensor is immersed in a solution being tested, the pH level at the electrode goes down because of the gluconic acid produced by oxidation of glucose in the solution. The field effect transistor detects the change and reads out the amount of glucose in solution. The process takes about two minutes. The use of semiconductor technology makes miniaturization and mass production feasible.

- Use of a Membrane Electrode as a Glucose Sensor - T. Yao, of Osaka University, constructed a chemically modified enzyme membrane electrode for glucose by cross-linking glucose oxidase with bovine serum albumin using glutaraldehyde on a platinum electrode silanized with 3-aminopropyltriethoxysilane. The response time is 10 s, the calibration graph is linear for 10^7-2 x 10^3 M glucose. The sensor can be

used repeatedly at room temperature for at least 30 days.

- Measurement of Glucose Oxidation - Researchers at Kyoto University have developed a way to measure the rate of glucose oxidation with the use of a fluidized-bed column placed in a magnetic field and magnetite containing beads of immobilized glucose oxidase and catalase. Its performance is predictable from the volumetric coefficient for liquid-phase mass transfer and the kinetic constants for glucose oxidation.

- NO_2 Sensor - S. Suzuki and coworkers of the Tokyo Institute of Technology have developed a biosensor consisting of immobilized nitrite oxidizing bacteria and an electrode for the amperometric determination of NO_2 gas. The response time for the determination of NO_2 is within three minutes. There is a linear relationship between the current decrease and the NO_2 concentration below 225 ppm. The minimum concentration of NO_2 that can be determined is 0.51 ppm.

- Measuring Waste Water BOD - Researchers at Ajinomoto Company have developed a biosensor that can measure the biological oxygen demand (BOD) of waste water. The sensor is composed of an acetylcelluose membrane and a type of yeast that reacts to organic pollutants. The oxygen consumed by the yeast indicates the quantity of organic pollutants present. The reaction is translated into electrical signals by the electrodes and then can be measured. This process has advantages over current measurement techniques because the entire process take place in about 30 minutes.

- GENE TRANSFER AND EXPRESSION

A research target for many applications of biotechnology is the extension of recombinant DNA techniques to new hosts, extending the expression of foreign genes in a host, or developing probes for the isolation and cloning of genes useful for industrial purposes. Recent research in Japan of this type is described below.

- Construction of a Vector for Cloning of Large DNA Fragments - Y. Takagi and coworkers of Kyushu University constructed a small packageable plasmid from ColEl-gal-cos λ::Tn3, pky 2113 which they named pky 2662. This plasmid carries ampicillin resistance and colicin El immunity genes as selection markers. The molecular size of the plasmid is 8.7 kb, and it has a single cleavage site for Bam Hl, Clal, EcoRl, Hpal, Pstl, and Tth 1111. Using pky 2662 as a vector, a 32 kb *Escherichia coli* DNA fragment covering thy A, rec C, rec B, and arg A genes was cloned.

- Construction of Plasmid Vector for Gene Expression in *E. Coli*- Researchers of the Kyowa Hakko Company have constructed a plasmid vector for direct expression of foreign genes in *E. coli* designated ptr S3. It carries the *E. coli* trp promoter and the Shine-Delgarno (SD) sequence for the trp leader peptide and an ATG sequence 13 bp downstream from the SD sequence. The dG residue of this ATG overlaps with the first dG residue of the single Sph I recognition sequence of the vector DNA. The foreign genes ligated to this vector DNA have been expressed in *E. coli*.

- Gene Splicing in *Seratia marcescens* - Researchers at the Tanabe Seiyaku Pharmaceutical Company have developed a host-vector system for *Seratia*

marcescens, a species used for amino acid production. This was accomplished by obtaining a host strain with enhanced transformation rate through selection for extra cellular nuclease deficiency. Using plasmids pACYC 177 or pBR 322 in which the aspartase gene is inserted, they were able to enhance aspartase activity 20 times.

- Gene Splicing in *Brevibacterium* - Researchers at Ajinomoto Company have developed a host-vector system for the *Brevibacterium*, thus extending recombinant DNA technology to this bacterium that is useful in amino acid production. *Brevibacterium* have been used by Ajinomoto for the production of glutamic acid by fermentation. Using recombinant DNA techniques to introduce different threonine genes, they have increased threonine production by 50% and believe they can increase production of this amino acid much higher. There are 10 amino acids that can be produced by fermentation with *Brevibacterium*. The vector and conditions of transformation are not revealed but the threonine genes that have been transferred to date are from *E. coli* and *Bacillus subtilis*.

- Gene Spilicing in *Corynebacterium* - Researchers at Kyowa Hakko have succeeded in developing a host vector system enabling them to splice foreign genes into *Corynebacterium*. They plan to use the recombinent DNA technology to enhance their capacity of amino acid production among other things. It should be noted that with the extension of recombinant DNA technology to *Corynebacterium* by Kyowa Hakko, to *Brevibacterium* by Ajinomoto, and to *Seratia* by Tanabe Seiyaku, the three leading amino acid producing companies have applied this new technology to their own bacterial system.

- Cloning of a Thermostable Alpha-Amylase Gene - The structural gene for a thermostable alpha-amylase from *Bacillus stearothermophilus* was cloned in plasmids pTB 90 and pTB 53 by researchers at Osaka University. The gene was expressed in both *B. stearothermophilus* and *B. subtilis*. In the former cells carrying the recombinant plasmid produced 5-fold more alpha-amylase than did wild type strains. No differences were observed in the enzyme properties produced by the two host species. In both host cells the alpha-amylase has a MW of 53,000 and retained about 60% of activity even after treatment at 90°C for 60 minutes.

- Human CRF Cloned - Professor S. Numa of Kyoto University has cloned the precursor gene of the corticotropic releasing factor (CRF). The precursor is a peptide having 196 amino acids, the 24 at the amino end form a signal peptide for its secretion. CRF itself is 41 amino acids which are the $154^{\underline{th}}$ to the $194^{\underline{th}}$ amino acids in the precursor. The gene has a 800 bp intron. The amino acid structure of CRF from sheep hypothalamus was determined and then 11 base and 14 base oligonucleotides were synthesized and used as a probe to detect mRNA and as a probe for cDNA. From over 1 million clones prepared, one contained the sheep CRF precursor gene. Human CRF was picked up from the library of human DNA made by Maniatis. CRF controls key events in the stress response and is implicated in stroke, heart and kidney diseases. An adequate supply of this molecule is the first step in developing a means to counteract its effects. Because it directly stimulates the pituitary to release corticotropin, human CRF is promising as a drug for studying pituitary function.

- Cloning of Complement Gene - Professor M. Takahashi of Kanazawa University and T. Honjo of Osaka University have cloned complement genes. Complement is a

general term for about 20 kinds of proteins in blood serum that are important effectors of immune reactions. The complement is activated when bound to an antibody. These researchers cloned complement 3 (C_3), MW 200,000 and complement 4 (C_4) MW 200,000 which hold a key to the reaction of complement activation. For C_3 they used cDNA of human and mouse liver. They cloned 2.6 kb of gene fragment which is half the length of the C_3 gene of the mouse and used this as a probe to isolate human C_3. For C_4 they extracted mouse liver cDNA using as a probe synthesized oligonucleotides based on the sequence of human C_4.

- Cloning of Human Gastrin Gene - Researchers at Osaka University isolated from a λ cosmid-derived human gene library a clone that contains the human fetal liver gastrin gene. This gene is 0.7 kb long and has one intron. The intron separates the coding region into a region essential for the biological activities of gastrin and a nonessential region at the N-terminal end of the peptide.

- Development of Host-Vector System for Lactic Acid Bacteria - Researchers at Meiji Milk Products Company discovered a plasmid in *Streptococus lactus* that can be taken up by *E. coli* and other lactic acid bacteria. Since lactic acid bacteria are widely accepted as safe and are eaten, this type of host-vector system is considered especially promising for the production of products ingested by humans such as drugs. Further, since the hosts are already used in the production of food such as cheeses, recombinant DNA techniques can be used to modify the flavor of cheeses.

- Transformation of Yeast Cells - Researchers at Kyoto University found that yeast cells treated with 2 mercaptomethanol could take up plasmid DNA. The experiments were carried out using the yeast strain *Saccharomyces cervisiae* D13-1A as the recipient and YRp7 as the plasmid DNA.

- Development of Potential Shuttle Vector for Plants - Researchers at Teijin, Ltd., are trying to develop a cloning vector for plants using the Gemini virus. This is a small DNA virus (2.7 kb) that infects leguminous plants. DNA has also been purified from Gemini-like viruses as the golden bean mosaic virus which causes infection in kidney beans and the mung bean yellow mosaic virus that causes infection in green beans. A single strand of DNA has been converted to double strand DNA by reverse transcriptase and cloned using pBR 322. To get infection in plants, two types of Gemini virus must be present--the A&B types. The researchers at Teijin have succeeding in splicing together the DNA from the A&B types essential for infection. They are now working on making a shuttle vector between *E. coli* and plants.

- PLANT APPLICATIONS

The use of cultured plant cells without genetic manipulation other than selection to yield products of commercial interest is not a popular approach to biotechnology in the U.S. The research described in this section is included in this report to show the potential of this approach. It is extracted from the author's site visit report of the center.

In 1982, the College of Agriculture, Kyoto University, established a new facility called, "Research Center for Cell and Tissue Culture." It is located in a two-story building at the edge of the campus with adjacent green houses and small field plots. It is organized into two major laboratories:

- Fermentation Cell Technology Laboratory, headed by Professor Yasuyuki Yamada, and
- Fermentation and Metabolic Regulation Technology, headed by Professor Yoshiki Tani.

The purpose of the center is to study fundamental and applied plant cell technology. It is intended to facilitate interdisciplinary research in which cell biologists, biochemists, geneticists, and microbiologists can interact. The labs are as finely equipped as any researcher could desire. The core thinking of the center is that by the use of cell culture methods, a new biotechnology will develop that is capable of improving crops and produce primary and secondary metabolites that can have industrial and agricultural uses. A sampling of some of the research carried out at the center follows.

. Production of Berberine

The crown jewel of the center's activity to date is the development of techniques for producing berberine in cells in culture. The techniques have now been transferred to industry where the cells are grown in 750 liter vats for commercial production of the alkaloid. In the Orient, herbal medicine has a greater role in medical practice (and therefore in the market place) than in the West. Berberine has been used as an antibacterial, antimalarial and an upset stomach drug. In the past, this drug has been obtained from the roots of *Coptis japonica*. It take five-six years to produce *Coptis* roots as a raw material for berberine extraction, so developing cell cultures as a resource is of important economic value. In their initial efforts they demonstrated that *Coptis* cells could produce the same amount of berberine on a dry weight basis as *Coptis* roots and in only three weeks. To increase this production for commercial purposes they initiated a clonal selection program, varying certain culture conditions until they achieved a 10% berberine production per cell on a dry weight basis or 12 mg per 10 ml of culture. Segments of the petiole and leaf of young *Coptis japonica* plants were cultured in the dark on solid Linsmaier-Skoog basal medium. Adventitious rootlets derived from these segments remained in an organized form during successive transplants to fresh callus-induction media. Dispersed cells appeared when small tissue segments that remained in the old medium after rootlets had been subcultured were themselves cultured on the same medium for a longer period. These cells grew better and produced more berberine in liquid than in solid culture. Through repeated clonal selection they established a stable, high berberine-producing culture. They found that light inhibited growth and berberine production, but a high degree of aeration stimulated both. Sucrose was the best carbon source for both cell growth and berberine production. (Fructose and glucose promoted growth, but not berberine production.) Purified berberine was identified and measured using its melting point and its UV, IR NMR and MS spectra.

. Production of Tropane Alkaloids

Tropane alkaloids are a distinct group of secondary metabolites of the solanaceae. Two of them, hyposcyamine and scopolamine are medically important for treating spasms and as anesthetics. Attempts to produce them in cultured cells in other laboratories have consistently resulted in cells with a lower content of the alkaloids than in the original intact plant. The Kyoto Center tested newly induced calluses of *Atropabelladonna, Datura stramonium* and *Hyoscyamus niger* for the alkaloids but only *H. niger* gave a positive test in one line out of 70. A

selection program on this line is in progress.

. Production of Biotin

A selection program for high content of free biotin was carried out in cells of ten species. With one species, *Lavandula vera*, they were able to get a 15-fold increase in free biotin levels after 11 repetitions of subcloning and selection. They used pimelic acid, a precursor of biotin which has a toxic effect on cultured *L. vera* cells, as a screening agent to select cells that could concentrate large amounts of free biotin. Culturing the cells under light maximized the biotin synthesis.

. Lipids of Culture Euphorbia Cells

Young shoots of *Euphorbia tirucalli* and leaves of *E. millii* were placed in Muroshiga and Skoog's medium supplemented with auxin and grown under fluorescent light at 28°C. Calluses appeared from the tissue after one to three weeks. These were transferred to fresh media every four-six weeks and kept for a year until they were analyzed for phytosterols, fatty acids and anthocyanin. The phytosterol fraction analyzed by GC-MS consists of 72% sitosterol, 25% stigmasterol, 2.5% campesterol and a trace of cholesterol. The fatty acid fraction contained palmitic and linoleic acids. The *E. millii* callus contained a red pigment which was shown to be cyanidin glycoside and has industrial potential as a natural dye.

. Salt Tolerant Rice Cells

Selection experiments were carried out to obtain salt tolerant lines of rice, *Oryza sativa.* Immature embryos were used to induce callus. The embryos, separated from the endosperm, were placed on agar slants containing Linsmaier-Skoog medium and six different concentrations of sea water. Incubation was at 28°C under continuous fluorescent light. Transfers were made every four weeks. One week after inoculation calluses had formed in all the media, but were smaller where the concentration of sea water was high. During subsequently subculturing, the calluses in the higher concentrations of sea water died. After four subcultures (four months) with sea water in the media, the cells were transferred to regeneration medium where some young plantlets developed. Plants grown in solutions containing 37.5% seawater grew for 10 days and then died. Plants grown in solutions containing 17.5% seawater survived, but the salt resistance declined in the next generation. They have concluded that salt tolerance can be selected for, but that they still have to solve the stability problem.

. Shikonin Derivatives Production

Shikonin derivatives from the roots of *Lithospermum erythrorhizon* are used as medicinals for wounds and burns and are also used as dyes. It was known that callus derived from seedlings of this species could produce these metabolitis. To see if an efficient method of producing these products in suspension cultures for industrial purposes could be developed, the center investigated various culture conditions affecting the production of these derivatives. Cell growth and yield of shikonin derivatives were measured in cells cultured in four different liquid media differing in the concentration of major nutrients. It was found that cell growth

was highest in one medium, but yield of shikonin derivatives was highest in another. To produce the metabolites more efficiently, they tried a two-stage culture method in which cells were grown first in one medium and then transferred to the second medium. This resulted in a 4.6 times higher production of the shikonin derivatives but culture duration was prolonged. They then varied the concentration of nutrients and have developed a new second stage medium which does not prolong cell growth and in which shikonin derivatives are produced at a level 13 times higher than previously. Mitsui Petrochemical Industries has scaled up the procedure.

. Cryogenic Preservation of Callus

The center has recently started research on methods of preserving plant cells that retain their physiological and biosynthetic properties for long periods in the frozen state. This is especially important in Japan where special importance is placed on the collection and maintenance of living resources (i.e., plant, animal, and microbial cells). Although there are central repositories, each laboratory shelters its unique collection. The development of cryogenic preservation would be a major contribution. To date the center has had success in storing callus at (-) 196°C up to three months. Thawing after this period resulted in 1-2% viability with biotin biosynthesis unimpaired. The trick seems to be to freeze slowly (1 degree per minute) until (-) 196°C and to thaw rapidly to prevent crystallization of water in the cells. The three month test period is not an experimental limit, but is the length of the experiment at the time of my visit.

- OTHER

In this section are summarized an assortment of research applications related to the food industry, agriculture, the chemical industry and biomass utilization.

. Disease Resistance in Tobacco - Researchers in the Plant Pathology Department of Kyoto University selected protoplast-derived calluses of tobacco for resistance to toxins from *Pseudomonas syringae* which causes wildfire disease, and from *Alternaria alternata* which causes brown spot. A number of plants were generated from each of the toxin-selected protoplast derived calluses. A larger percentage of the plants obtained from the second selection cycle calluses were resistant to infection to these pathogens. The resistances are heritable and are independent of each other.

. Aspartame via Bacteria and a Fungus - Researchers at the Toyo Soda Manufacturing Company, have isolate strains of bacteria to make aspartame--a low-calorie sweetener rapidly replacing saccharine. The microbes enzymatically convert an amino acid and a related compound, both costing a few dollars a pound, into aspartame which sells for $100 a pound. Aspartame is 180 times sweeter than sugar. A chemical process that condenses aspartic acid and the methyl ester of phenylalanine into a dipeptide sweetener employs "protective radicals" that are "troublesome" to remove from the final product and produces "optical isomers," of the end product that generally are not biochemically active. Microbial production obviates both of these problems. Toyo researchers identified at least two species of aspartame-synthesizing bacteria, *Pseudomonas putida* and *Alcaligenes faecalis*, plus the fungus *Sporobolomyces odorus*. Working with *P. putida* TS-15001, they found that five g of resuspended bacteria produced 0.1 g of

aspartame after six hours at 37°C. The medium initially contained 3.3 g of aspartic acid and 4.5 g of phenyl alanyl methyl ester, the unconnected components of the dipeptide sweetener.

- Single Cell Protein from Algae - Researchers at Dainippon Ink and Chemicals, Inc., use a new shuttle vector to increase the pigment and vitamin content of *Spirulina*, a blue-green alga. This animal fodder and human health food contains 60% to 70% protein by dry weight. In Japan, the photosynthetic single cell protein is used as a high pigment feed in fish farming. The company plans to use *S. platensis* and *S. siamese* as hosts for gene manipulation. Combining a fragment from a spirulina plasmid with pBR 322, Professor M. Sugiura of Nagoya University has developed a shuttle vector between the bacterialike alga and *Escherichia coli*. By improving the products nutritional value by genetically increasing its beta-carotene, phycocyanine, and vitamin B12 content, the value of this food should increase.

- Production of Cyanocobaramin by Fermentation - Cyanocobaramin is a particular form of vitamin B12 and is used to treat pernicious anemia. Researchers at Nippon Oil Company have succeeded in isolating and refining this compound. Using dextrose as the raw material, it is fermented by a particular actinomyces to produce vitamin B12. Cyanocobaramin which is a high molecular weight form of B12 is purified by use of a special liquid chromatography separator.

- Production of Hypertension Associated Proteins - Professor S. Nakanishi of the Kyoto University Medical School has cloned human renin, a peptide implicated as a high blood pressure trigger. The cloned sequences code for 406 amino acids. The first 20 amino acids are a signal peptide; the next 46 are a preprotein segment, followed by the renin A&B chains of 293 and 47 amino acids respectively. Dr. Nakanishi is also trying to clone the enzyme angiotensinogen, associated with high blood pressure. The goal of this research is to get enough of these proteins to determine their three-dimensional structures and then design specific inhibitors to them for use as a drug against hypertension.

- Innova+ion in Vaccine Production - A method for producing vaccines that are free of allergenic side effects has been developed by the Institute of Public Health (Tokyo, Japan) and Hayashibara Biochemical Laboratories, Inc. (Okayama, Japan). The method conjugates saccharides or polysaccharides with biologically toxic substances to form a vaccine that is safer and less expensive than ones made by the conventional formalin method. The method can be effectively applied to a variety of pathogenic bacteria and toxins.

- New Restriction Enzyme - A new endonuclease, critical to the jumps and reassembly of gene segments that enable the body's B cells to make diverse antibodies, has been discovered by Professor Honjo of Osaka University Medical School. He found the enzyme, "recombinase," in the chick bursa of *Fabricius*. This is a thymuslike gland in fowl that produces precursor B lymphocytes. These white blood cells make antibodies. To find his new type restriction enzyme, Honjo used an *E. coli* plasmid carrying the genes for the immunoglobulin's light chain variable region (V) and joining segment (J) along with a Streptomycin-resistance gene as a selectable marker. These V and J DNA sequences are far apart in the mammalian chromosome, but get snipped and stitched together when B lymphocytes are activated to churn out antibody of a precise specificity. He

treated this cloning vector with cell extracts from the bursa of *Fabricius*, which led to fusion of the V and J segments.

- A New Restriction Enzyme - Researchers at the Yakult Honsha Company have isolated, purified, and are marketing a new restriction enzyme from *Lactobacillus bifidus*. The company claims this enzyme is a new type of restriction enzyme which can recognize a cleavage site sequence in DNA that is different from that of other known restriction enzymes.

- Long-term Preservation of Fungal Cultures - Y. Miura of the Institute of Applied Microbiology has successfully preserved 544 stock cultures of *Mucor*, *Rhizopus*, and *Aspergillus* for ten years. Using a paraffin oil preservation technique, that is, oil-covered slants, he observed the following survival rates: 90 *Mucor* cultures (29 species) 92% survival, 287 *Rhizopus* (20 species) 44% survived and 167 *Aspergillus* cultures (72 species) 56% survived.

- Solid Phase Gene Synthesis - H. Takaku of the Chiba Institute of Technology developed a new manufacturing technique for synthesizing genes. Normally solid phase processing involves the binding of nucleotides at the end of a polymer such as amidomethyl, silica gel, or polyacrylamide. The Takaku method uses an oxime resin, a polymer with a high support rate and short separation time. The polymer is a polystyrene with an oxime group introduced as a reactive group by adding 1,2 dichloroethane and p-nitrobenzoyl chloride to polystyrene. Its support rate is the binding of 350-400 micromoles of nucleotide per gram of oxime polymer and is capable of linking 15 nucleotides in one condensation reaction. When hydrazine compounds are used, separation is accomplished in 15 minutes.

- Laser Aided DNA Transfer - Researchers at the Institute of Physical and Chemical Research have developed a method for introducing DNA into cells without using vectors. Basically the method involves placing recipient cells in a solution containing the DNA and bombarding each cell for 1/100 millionth of a second with a 355 nm wavelength beam from a yttrium-aluminum-garnet laser. The laser drills a hole about one micron in diameter which closes itself within a second. While the hole is open the DNA from the surrounding solution enters the cell. The laser and microscope are automated so that an operator just has to locate a cell on a TV monitor and point a light pen at the displayed cell for the laser to drill the hole. According to the researchers, as many as 2000 cells can be processed in a few minutes. The researchers claim that at least one cell bearing a recombinant gene is produced for every 200 cells processed by the new technique or about 10 times the success rate with conventional techniques. Other advantages of the laser drilling method over techniques like micro injection, pin drilling, and chemical softening of cell walls include less risk of damaging the cells and less skill being required to perform the technique.

- *E. coli* Engineered to Secrete rDNA Proteins Externally - Researchers of the Institute of Physical and Chemical Research have found a way to make *Escherichia coli* secrete proteins in large quantities into the culture fluid. The discovery resulted from work, started four-and-a-half years ago to produce the enzyme *penicillinase*. The researchers isolated a gene from an alkalophilic bacillus, which when inserted in *E. coli* cause the *E. coli* to secrete proteins. The researchers spliced the 2000 base pair gene for secretion into the PMB 9 plasmid along with the gene for penicillinase and inserted the hybrid plasmid

into *E. coli*. As a result more than 80% of the penicillinase produced by the *E. coli* was secreted externally with about ten other naturally occurring nonsecretory proteins. The plasmid containing the secretion gene is designated pEAP2. The secretion gene comes from a proprietary organism identified only as "alkalophilic bacillus 170."

- Production of Alcohol Biomass - The Kyowa Hakko Kogyo Company has begun a biomass project using raw material grown on Tinian Island, one of the Northern Mariana Islands in the South Pacific. The company has leased 195 hectares from the local government and is clearing the forest and growing sweet sorghum on the cleared land. Sweet sorghum which has a cultivation time of four months is a good producer of molasses by microbial fermentation. The company currently imports 150,000 tons of molasses per year from Southeast Asia as raw material for the production of alcohol and amino acids by microbial fermentation. The Tinian Island source of raw material will make the company self-sufficient for molasses and they eventually plan to cultivate 2000 hectares of cleared land.

- Alcohol Fuel from Biomass - The New Energy Development Organization (NEDO) has commissioned a project on fuel alcohol production by bacterial fermentation of waste molasses from sugar cane. The conventional method of alcohol production uses yeast, but the process developed through the New Energy Development Technology Research Association uses bacteria that gives a high yield. They are currently trying to develop super bacteria that will produce even greater yields from cellulosic material including rice straw, rice hulls, and scrap wood. In the pilot studies, the bacteria are loaded on mica packed in very large containers and the starting material is continuously fed into the fermentation tank to continuously produce the alcohol. The first industrial-scale plant will be located in Okinawa.

12TH INTERNATIONAL CONFERENCE ON PHOTOCHEMISTRY

Kenneth M. Sancier

INTRODUCTION

The 12th International Conference on Photochemistry was held from 4-9 August at Sophia University, Tokyo. The conference was organized by representatives from many countries and the chairman of the local organizing committee was Professor I. Tanaka of the Tokyo Institute of Technology. The conference was attended by 600 people, and the papers, which were all in English, covered a wide variety of topics, 158 were presented orally and 370 in poster sessions. The costs of the conference were partially subsidized by Japanese scientific organizations and by a group of industrial companies.

Several satellite meetings were held in connection with the main conference:

- Sendai Symposium on Organic photochemistry, 1-3 August, was organized by Professor T. Mukai of Tohoku University, Sendai,

- New Aspects of Laser Chemistry and Dynamics of Excited Molecules, 2-3 August, was organized by Profeessors K. Yoshihara and N. Nishi of the Institute for Molecular Science, Okazaki,

- the International Meeting on New Aspects of Photochemistry and its Applications, 12-14 August was organized by Professor H. Shizuka of Gunma University, Kiryu, Gunma, and

- the Meeting on Photoinduced Electron Transfer and Related Phenomena--Fundamental, Functional and Biological Aspects, 12-13 August, was organized by Professor N. Mataga of Osaka University, Toyonaka, Osaka.

The 13th International Conference on Photochemistry will be held in 1987 in Budapest, Hungary, and will be organized there by Professor Ferenc Marta of the Central Research Institute for Chemistry, Pusztaszeri ut 59-67, Budapest.

CONFERENCE PROCEEDINGS

The subject material presented in the main conference at Sophia University was subdivided into the following categories:

surface and matrix photochemistry
mechanistic approaches to organic photochemical reactions
photophysics in polymer and molecular assemblies
multiphoton processes
photophysics and spectroscopy
applications of photochemistry, photoresist, etc.
magnetic resonance
photooxidation
electron transfer and preparations
organized media
photochemical kinetics
photophysics of large molecules

preparative organic photochemistry
biological aspects of photochemistry
photophysics and multiphoton kinetics
photochemical kinetics in solutions
interfaces

Abstracts of all the papers presented at the main conference were provided. It is virtually impossible to report on the relative merits of presentations at a conference with such a wide scope. I report below on selected topics which I feel qualified to evaluate and also on those which were recommended by colleagues with complementary qualifications. The topics below have been subdivided into groups for the convenience of discussion.

- Laser Applications

The topic of new laser techniques in photochemistry was reviewed in a plenary lecture by V. S. Letokhov of the Institute of Spectroscopy, U.S.S.R. Academy of Sciences. Developments in basic science using lasers include, (1) the study of excitation of molecules in multistep or multiphoton processes, (2) probes of highly excited molecules including Raman spectroscopy, and (3) detection of primary products of photodissociation. For such studies, UV and IR lasers have recently been used in combination. Several examples of practical applications were given:

- isotope separation of ^{13}C from CF_3Hcl containing 1.1% of the isotope has been achieved by multiple photon dissociation using two-color IR and achieving an enrichment factor of 98%, a production rate of 15 kg/yr per kW of laser power, energy consumption of 2-4 keV/C, and cost of USA$8/g,

- radical synthesis by means of an IR multiphoton laser, for example,
  $(CF_3)_3CBr$ ----> $(CF_3)_3C^\circ + BR^\circ$
  The advantages of production of such radicals by laser rather than thermal processes include: lower energy consumption, one versus ten stages, higher yields, and repetitive cycling is possible,

- lasers are now in common use for surface etching and chemical vapor deposition (CVD) of semiconductor devices, and

- biological and medical applications.

The topic of laser-induced etching and deposition was illustrated in a paper presented by Jun Tokuda of the Faculty of Engineering Science, Osaka University, Toyonaka. Laser-induced micro etching and deposition have attracted much attention because, (1) low temperature and maskless processes are possible, (2) laser beams constitute cleaner energy sources in comparison to ion beams or plasmas which induce lattice defects or incorporate impurities, and (3) narrow lines can be etched or deposited by laser beams. The pyrolytic local etching of GaAs with a focused Ar laser beam in CCl_4 or $SiCl_4$ gas was studied to investigate the possibility of maskless etching of GaAs and the mechanism of etching and deposition. The maximum etching rate was 40 μm/s, which was greater by three orders of magnitude than by ion or reactive ion beam etching. The minimum line width was 0.6 μm which was narrower than the laser beam diameter (1.2 μm).

The development of laser mass spectroscopy for use with laser CVD was discussed by M. Stuke and R. Fantono of the Max-Planck-Institut für Biophysik and Chemic, Göttingen.

They reported work on fast, sensitive, and selective fingerprint detection of organometallic precursors of III-V and II-VI semiconductors, with emphasis on alkyl compounds of Te, Se, Ga, In, and As, using short (ns) and ultrashort (ps) single pulses from a tunable dye laser controlled time-of-flight mass spectrometer. Parent molecular ions could be detected using picosecond pulses.

Potential applications of lasers to medicine was summarized in a paper on ablative photodecomposition of biological tissue by R. Srinivasan of IBM, T. J. Watson Research Center, New York. Although he was unable to attend the conference, the abstract of his paper contained some stimulating material. The central point made is that while IR and visible lasers are already in use in medicine, the UV laser offers new possibilities. He illustrated by showing the cross section of cuts made in tissue by UV (193 nm) and visible (532 nm) lasers. The UV laser produced a narrow trench with very well defined straight walls and controllable depth, while the visible laser produced an irregular shape. The author suggested application of the UV laser technique to include angioplasty to remove calcified plaque from arteries, neurosurgery, and surgery of the skin.

- Organic Photoconduction

Applications and properties of organic photoconductors was the subject of a plenary lecture by R. O. Loutfy of the Xerox Research Center of Canada, Ontario. He emphasized that in view of the current intense technological interest in near infrared sensitive photoreceptors for solid state laser printers, there is a continued need for simple, reliable, inexpensive and nontoxic IR-photosensitive materials. He reported their work on two types of organic pigments, squaraines and metallophthalocyanines, that exhibit some promising behavior for xerography.

A novel molecular photodiode consisting of three different kinds of surfactant monolayers--electron donor (D), electron acceptor (A), and sensitizer (S)--that attempts to reproduce artificial photosynthetic molecular systems, was reported by M. Fujihira and K. Nishiyama of Tokyo Institute of Technology, Tokyo. When the order of depositing the surfactant layers was A, S, and D on a gold electrode surface, anodic photocurrents were observed as expected; but when the surfactants monolayers were deposited in the reverse order, a cathodic photocurrent was observed.

A novel electrode/membrane supported by conducting polyprrole polymer (PP) provided new functions depending on the high conductivity of PPy was reported by T. Shimizu, *et al.*, of the Division of Molecular Engineering, Kyoto University. Zinc tetra(4-sulfophenyl)porphyrin was efficiently incorporated into a positively-charged PPy matrix. This electrode in a ferro/ferri cyanide solution was responsive to visible light with a quantum efficiency of about 0.1% at 435 nm.

A technique for studying unstable photochemical intermediates using polymer film matrices was described by A. J. Rest of the University of Southampton, U. K. The technique, which is an improvement over the usual isolation method using rare gas matrices, depends on doping substrate molecules into thin solvent cast polymer films. Photolysis of such matrices generates unstable species whose thermal reactions can then be monitored over the range of 10-293 K.

- Photocatalysis on Semiconductor Surfaces

Laser flash photolysis coupled with time-resolved diffuse reflectance spectroscopy

was used by F. Wilkinson of the Loughborough University of Technology, Leichestershire, U.K., to investigate photoproduction of transient charge-transfer complexes. In one set of experiments, they studied photolysis of aromatic hydrocarbon on the surface of alumina and of acridine on silica. These studies were made by measuring the transient adsorption spectra of the laser excited molecules on the solid surfaces. In other experiments, they investigated intrazeolite photochemistry in which organic ketones are adsorbed on the surface of hydrophobic zeolite silicatite. By measuring the phosphorescence decay, they were able to obtain information on the mechanism of triplet-triplet decay that in some cases was due to multiple surface sites.

Pulsed laser studies of gas-surface interactions were reported by W. M. Jackson, *et al.*, of Howard University, Washington, D. C. Using a combination of pulsed lasers and pulsed molecular beams they were able to investigate surface processes that occur on a very short time scale, thus opening the possibility of studying surface kinetics and diffusion. Gas-surface systems studied include H_2, BrCN, ClCN, and C_2N_2 on Si<111>.

Two reports were made concerning photocatalytic isomerization on semiconductors with the objective of obtaining basic information on photocatalysis. Tokumaru, *et al.*, of the University of Tsukuba, Ibaraki, reported that cis-to-trans photoisomerization of aromatic olefins in acetonitrile occurred in the presence of TiO_2, CdSe, CdS, or WO_3. The isomerization was explained in terms of electron or energy transfer from the excited semiconductor to the olefin. Kubokawa, *et al.*, of the University of Osaka Prefecture, Osaka, reported on photocatalytic isomerization of butenes over TiO_2, CdS and ZnS, for which both cis-trans and double bond isomerization occurred. The mechanism of photoisomerization is explained by photoproduced OH° radicals and O^- species at the surface. The difference in activity and product distribution between the oxides and sulfides may be due to the differences in the acidity of the OH and SH surface groups.

Many surfactants cause severe pollution problems in aquatic environments. In an attempt to solve this problem, M. Grätzel, *et al.*, of Institut de Chimie Physique, Ecublens, Switzerland, had been working on the photocatalytic degradation of surfactants by TiO_2 particles. They showed that the surfactant, sodium dodecylbenzene sulfonate, was efficiently photodegraded by an anatase suspension, and oxygen was required for complete decomposition. They demonstrated that a toxic pesticide, 4-chlorophenol, could also be photocatalytically decomposed efficiently on anatase. The mechanism of this photocatalytic oxidation is believed to involve trapping of photoproduced holes by surface hydroxyl ions giving OH° radicals along with trapping of photoproduced electrons by oxygen with formation of absorbed O^-.

In response to the current interest in photocatalysis on semiconductor surfaces, I presented a paper describing several ways by which the electron spin resonance (ESR) technique can be used to investigate photoinduced charge transfer reactions between the surface and the bulk of semiconductors. Relevant information is obtained about sorbed species, surface states, and participation of donors and acceptor states of the bulk by combined *in situ* measurements by, (1) conventional ESR, and (2) by specialized techniques for measuring changes in electrical conductivity of the semiconductor that results from charge transfer reactions. Examples of various photocatalytic gas-solid systems were given; (1) the use of semiconductors such as ZnO and TiO_2, and (2) various photocatalytic systems including vacuum-UV damage to the semiconductor and photocatalytic oxidation of organic surface adsorbates.

- Amorphous Silicon

Hydrogenated amorphous silicon (a-Si:H) and a-Si:H alloys have attracted much attention because they are potentially good materials for low cost, high efficiency solar cells. The trend is toward photochemical vapor deposition (CVD) of silicon and away from the traditional glow discharge CVD which results in damage to the a-Si films. In one paper, H. Tarui, *et al.*, of the Research Center, Sanyo Electric Company, Osaka, reported on photo-CVD from Si, B, and Ge hydrides with Hg light that result in films with good homogeneity. Solar cells were fabricated with improved collection efficiency of short wavelength light, and also the indium-doped surface layer had a sharper concentration profile than produced by glow discharge.

In another paper, K. Kumata of the Electrotechnical Laboratory, Ibaraki, reported on the use of an ArF laser to induce CVD in silanes to produce a-SiH films with good electronic properties, about equivalent to that produced by a Hg lamp. Moreover, the ArF laser provided a deposition rate which is at least 20 times greater than that of the Hg lamp.

- Applied Photochemistry

To emphasize the importance of applied photochemistry, a special section was organized to cover developments.

Nonbiological systems capable of reducing carbon dioxide are of considerable interest as a means of transforming this abundant raw material into fuels and organic chemicals. C. Kutal of the University of Georgia reported on a mechanistic study of a system, $ReBr(CO)_3(bipy)/TEOA/DMF/CO$, that had been reported by Lehn *et al.*, in 1983, to have high chemical specificity. The results of the present study indicate that continuous photolysis at 436 nm results in the formation of CO with a quantum yield as high as 0.15.

A paper describing a new class of photochromic compounds sensitive to laser-diode wavelengths was presented by J. Seto, *et al.*, of Sony Corporation Research Center, Yokohama. They prepared and examined a variety of photochromic spiropyran compounds which absorb light at laser-diode wavelengths and are thermally stable even at room temperature. They report that for a 10 mW laser-diode (780 nm), 0.15 J/cm^2 of energy was required to change the reflectance by 20%.

As the minimum feature size for semiconductor device fabrication is reduced to the micrometer and submicrometer region, the requirements of photoresist systems become more difficult to meet. Several papers addressed this problem. The chemistry occurring during polymer surface reactions with hydrogen and oxygen under UV-light, electron, or ion beam irradiation was the topic of a paper presented by H. Hiraoka of IBM Research Laboratories, San Jose, California. K. Nate, *et al.*, of Hitachi, Ltd., Yokohama, described a double-layer resist system using the new family of positive deep UV resists based on poly(p-disilanylenephenylene), which strongly absorb at wavelengths less than 300 nm. The photoproduced polymer films have extremely high resistance to oxygen reactive ion etching. A paper by K. Mori, *et al.*, of the Kanto Chemical Company, Nagoya, described a reverse development negative photoresist using a conventional wet development process.

INTERNATIONAL SYMPOSIUM ON OCEAN SPACE '85

Norman D. Albertsen

INTRODUCTION

During the week of 3 June 1985, Nihon University in Tokyo, Japan, hosted an international symposium on ocean science and technology. The symposium was attended by over 600 scientists and engineers from nations around the world. During the four days of the symposium, 160 ocean-related papers were presented; while approximately 100 of these were authored by Japanese writers; in all, 16 countries contributed at least one paper. A two-volume symposium proceedings has been published by Springer-Verlag.

In the keynote address, Professor W. Kato of Nihon University set the tone for the conference. He stated that in addition to looking at the ocean for materials (minerals, etc.), energy, and food, the Japanese also see the ocean as a fourth resource and that resource is space. The purpose of the symposium then was for scientists from all over the world to exchange ideas and to cultivate and develop the science and technology required to exploit the resources of the world's oceans for the benefit of society.

SYMPOSIUM OUTLINE AND OVERVIEW

- Keynote Address

- Special Session
    - Ocean Space Utilization by Offshore Structures
    - Review of Ocean Space Utilization Projects

- Technical Session: Applied and Structural Mechanics in Ocean Environments
    - Hydrodynamic Forces
    - Wave Analysis and Estimation
    - Dynamic Response to Floating Structures
    - Wind and Current Forces
    - Fluid Structure Interaction
    - Solid Mechanics and Foundation Engineering

- Technical Session: Related Fields and Associated Studies
    - Ocean Energy Resources
    - Maritime Resources
    - Safety Engineering
    - Remote Sensing Data Correlation/Analysis Measuring Devices

- Technical Session: Coastal Zone Utilization and Management
    - Coastal Zone Management
    - Coastal Zone Planning
    - Development Project and Planning
    - Coastal Processes
    - Environmental and Safety Management
    - National and Regional Planning

- Technical Session: Materials and Construction
    - Design of Concrete

Durability of Concrete
Construction
Corrosion and Protection
New Concepts
Ocean Structures

Each technical session had an international flavor with papers and presentations from several countries in each session. Unfortunately, not every paper submitted and included in the symposium proceedings was presented at the conference by the author of those papers. The two cases which come to mind are an excellent paper from Australia on "Foundation Problems in Marine Calcareous Sands," and a paper from the U.S.S.R. entitled "Soviet Submersible Research of Oceanic Rift Zones."

In general, the papers seemed to be more technically meaningful than the presentations. I feel this is at least in part due to the loss of some technical detail in the on-the-spot translations during the symposium. Overall, the symposium was well organized and technically very rewarding and beneficial.

SYMPOSIUM HIGHLIGHTS

In the special session, Professor John Craven of the University of Hawaii in his paper entitled "The Sea-based Village, an Engineering and Economic Reality," makes the point that the technology is now available to "build small area, sea-based communities which employ the resources of deep cold water [and] will have an economic source of fresh water, energy and marine protein...and will have parklike and esthetic configurations both above and below the surface of the sea."

A second paper in the special session entitled "Ocean Communication City (OOC)" by Dr. K. Terai of the Nippon Telegraph and Telephone Corporation (NTT) extends the small sea-based community idea to a city-sized marine structure, 5 km by 5 km set in the ocean "scores of kilometers [from] the mouth of Tokyo Bay." The structure would have four decks and would be both a home and work site for from 500,000 to 1,000,000 people. [See "Scientific Bulletin Briefs," *Scientific Bulletin, 9* (4), 1 (1984).]

Two other papers in this session examine the technical issues related to large offshore man-made islands and the benefits of using an offshore island as a base for offshore fisheries. Both papers express a strong theme of feasibility and need, from the Japanese point of view. A final paper in the first day's special session dealt with the development of a long-range autonomous submarine called the *Saga I*. This submarine will be 28-m-long, have a displacement of 550 tons, will be capable of up to 150 nautical miles of submerged travel and be able to release divers and tools at a depth of 450 m or robots up to 600 m. The submarine is envisioned to be a support craft for all types of ocean construction. The submarine development is a combined effort of COMEX and the French National Agency for Ocean Development. The development began in 1982 and will be completed in 1987 with an operational demonstration. The submarine represents an "all-underwater" solution to many presently difficult offshore tasks and should be a valuable asset to the ocean-oriented engineering and construction community in the near future.

Other special session papers under the heading of "Technologies for Utilizing Ocean Space" addressed the need to pay more attention to offshore safety and provided information on computer simulations for mooring systems and the hydroelastic behavior of

marine structures. These specialized ocean-related problems were discussed in detail and provided information on each topic valuable to those who either work in the ocean or design structures/systems for use in the ocean.

In the technical session entitled "Applied and Structural Mechanics for Ocean Environments," nine papers addressed hydrodynamic force related topics. Emphasis here was on procedures to calculate the forces on ocean structures resulting from waves and from structure motion. The analytical techniques described show advancements in the technology which will be of value to the structural designer. Nine additional papers are directed at "Wave Analysis and Estimation." These papers centered on the methods which can be used to numerically describe ocean waves. These techniques can be used by the designer to help configure ocean structures. Under the heading of "Dynamic Response to Floating Structures," seven papers examined the methods to predict the response (motion and forces levels) of fixed and floating ocean structures. Three additional papers addressed wave and current forces and the hydrodynamic response of floating, semisubmersible, and bottom resting ocean structures. Additional topics addressed in a dozen papers in the "Fluid-Structure Interaction" area were on earthquake-related problems. Finally, under the heading of Soil Mechanics and Foundation Engineering, eight papers concerning geotechnical site surveys, foundation engineering, anchor development, scour protection, and the influence of environmental factors on soil pore pressure and soil liquification were presented. The highlight here was a paper by Zen and Umehara entitled "Analysis on Wave Induced Pore Water Pressure in Sand Layers under Breakwater." The paper presents a combination of field and laboratory data, model tests, and finite element analysis to establish the cause of the failure of a caisson breakwater in storm action.

In the technical session entitled "Related Fields and Associated Studies," topics related to ocean energy, resources, safety, and remote sensing were examined in four subsessions. In the "Ocean Energy Resources" subsession, ten papers addressing wave energy, ocean thermal energy conversion, energy from tidal currents and neutrino detection were presented. Interest was high in this session for obvious reasons. If reasonable amounts of economical energy can be extracted from the ocean, the countries with this energy resource will be less dependent upon other sources. The papers in this session principally addressed the technical problems associated with energy extraction schemes. However, one paper described a wave power system (TAPCHAN) now under construction in Norway. Unfortunately, this paper and the presentation were used as an attempt to market the technology. The paper on Project DUMAND provided a status report on an international effort to develop an ocean-based target detector for very high energy neutrino interaction. Neutrinos are elementary particles which have no charge or mass and are a billion times more copious than the protons and electrons which make up ordinary matter. This is an interesting topic from a ocean engineering standpoint because it presents significant challenges in the form of design and construction of the 250 m x 250 m x 500 m ocean-based array needed to detect point sources of neutrinos in space.

The subsession on maritime resources provided five papers on topics associated with extracting ocean fish resources or source control. These papers were all prepared by Japanese authors and provide an indication of the interest in Japan in ocean resources and the high level of technology being developed in this area by the Japanese.

The last two subsessions addressed safety engineering, remote sensing, analysis measuring devices-related topics. Safety engineering was presented both from the point of view of the safety of structures such as bridges and piers in areas of ship traffic and from the point of view of the safety of ships in storm conditions. The remote sensing subsession

discussed methods for predicting oceanographic parameters from satellite data and what some of this data means in terms of the distribution and migration of pelagic fish and how this data can be utilized to assess environmental changes due to urban coastal development. A final paper in this subsession presented results of investigations of oceanic rift zones using a deep diving submersible.

In the technical session entitled "Coastal Zone Utilization and Management," issues related to waterfront and coastal zone management, planning, coastal processes, environmental and safety problems, and national and regional considerations were addressed. Specific topics ranged from revitalization of waterfront facilities to coastal environmental policy (waste dumping, etc.), economic conflicts in the coastal zone, population dynamics, and the influence of population on coastal zone management. This session was truly international with experts from a number of countries (U.S.A., Taiwan, Kuwait, India, Japan, Belgium) presenting papers and providing information on actual installations and case studies. The session papers should be of high value to those interested or involved in coastal zone development or planning.

The final session of the conference concentrated on materials and construction. Two of the subsessions here and a part of a third (a total of 15 papers) examined the issues associated with using concrete as a construction material in the ocean. Of specific interest were the material's water tightness and its long-term durability in the seawater environment, i.e., the ability of concrete and its internal reinforcement to withstand the cyclic loading environment typical in the ocean due to waves and the corrosive effects of salt water. The conclusion which can be drawn from the papers on concrete is that it is an excellent material for use in the ocean if sound engineering practices are used in the design of the concrete structural elements and the concrete mix (proper materials and proportions, etc.) and proper quality control is exercised in concrete placement and curing.

A second major topic (16 papers) in this session was on the use and protection of steel elements and structures in the ocean. Here emphasis was placed on examination of the corrosion process, development of coatings, paints, etc., to reduce or eliminate the corrosion problem and an examination of the cyclic fatigue problem common in the ocean environment. It is clear that the materials technology being developed for ocean application is producing the methods and materials to better use both concrete and steel in the ocean.

SUMMARY

In summary, this was an excellent, well organized conference. The international participation provided an opportunity for engineers and scientists who under other circumstances may never meet, to not only come together but to present their views and exchange ideas.

FOURTH INTERNATIONAL CONFERENCE STRUCTURAL SAFETY AND RELIABILITY ICOSSAR '85

Edward Mark Lenoe

INTRODUCTION

The Fourth International Conference on Structural Safety and Reliability was conducted at Kobe, Japan, 27-29 May 1985. The organizing institution was the International Association for Structural Safety and Reliability (IASSAR). This fourth conference follows the great tradition initiated by the late Professor A. M. Freudenthal who was responsible for the first conference in Washington, D.C., in 1969. The second conference was held in Munich in 1977 while the third was conducted in Trondheim, Norway, in 1981. The fifth ICOSSAR conference is scheduled to be held in San Francisco in the fall of 1987. It is noteworthy that each of these conferences has made significant contributions to the scientific literature, and the fourth ICOSSAR was an extraordinary event in that regard. The conference organizers and the various committees are to be commended on a fine job. About 250 abstracts were received in response to a call for papers, and the Scientific Committee reviewed, accepted or rejected, and organized these submissions into a three-day conference consisting of 52 sessions and 213 papers. What is most impressive is their efficiency in producing, within a one-year period, and in time for distribution at ICOSSAR '85, the three-volume conference proceedings. These hardbound volumes are a must addition for the library of any serious student of structural safety and reliability. For the benefit of the reader, ordering information is as follows:

> *Structural Safety and Reliability* (Volumes *1* through *3*) edited by Professors I. Konishi, A. H-S. Ang, and M. Shinozuka, (IASSAR, Department of Civil Engineering and Engineering Mechanics, Columbia University, New York). The printer is the Shinko Printing Publishing Company and the Agency is the ICOSSAR '85 Office, Japan Material Institute. The price is, for three hardbound volumes, 45,000 yen per set (mailing fee included).

- Purpose and Impact of the Conference

Achieving acceptable safety and reliability in the vast array of modern systems applications, while giving due consideration to economic limitations, is a matter of imposing and increasing concern. While the community of practicing structural reliability experts is comparatively small, this meeting attests to the fact that the community is a vital and growing community of engineers and scientists since 484 participants from 20 countries convened at ICOSSAR '85. The tabulation below lists the countries and numbers of participants.

SUMMARY OF ICOSSAR '85 PARTICIPATION

Country of Origin	Number of Participants
Japan	318
U.S.A.	72
People's Republic of China	16
Italy	13
Canada	10

Federal Republic of Germany	9
Norway	8
Holland	7
U.K.	6
France	4
Denmark	4
Austria	4
U.S.S.R.	3
Australia	2
Singapore	2
Spain	2
Poland	1
Egypt	1
Israel	1
Mexico	1
20 Countries	Attendees 484

A major accomplishment of ICOSSAR '85 was to provide a forum bringing together the expert practitioners and emerging talent and compiling their contributions. In this regard, the Proceedings of the conference are a valuable study aid since the technical contributions cover the spectrum of capabilities ranging from relative newcomers to the most advanced levels of sophistication. Of course, some of the newcomers present topflight research results. The presentations provide examples of reliability analysis of many important modern structural systems such as aircraft, nuclear power plants, bridges, buildings, marine oil drilling platforms, ships, space structures, and geological foundations. In addition, the conference placed great emphasis on the role of leading new materials for the design of more effective, safe, and reliable high performance structures.

Regarding participation from Warsaw pact attendees, some meaningful technical dialogue was achieved. The senior technical representative from the U.S.S.R. asked numerous penetrating questions, indicating a high level of sophistication and experience.

- Discussion

Each day, the meeting consisted of a keynote lecture, followed by simultaneous technical sessions and current research sessions. The keynote lectures were all well done and well received. The first keynote address was presented by T.L. Moser, director of engineering, NASA Johnson Space Center, and was entitled, "Reliability Engineering of the Space Shuttle: Lessons Learned." The second was presented by F. R. Farmer, ex-head of safety and reliability directorate, United Kingdom Atomic Energy Agency, while the third keynote address, "Reliability-based Antiseismic Analysis of Structures," was given by Takuji Kobori, Professor Emeritus, Kyoto University.

The lecture concerning the space shuttle attracted a large audience. Moser's presentation was high caliber and used top quality visual aids, including an interesting film strip on the shuttle launch and details of the thermal stress analysis of critical shuttle regions. From the viewpoint of reliability analysis, the approach presented relied on normal probability modeling, used empiricism where required, and generally speaking employed state-of-the-art methodology. Structural integrity criteria which emerged during the development of the shuttle structure and the thermal protection system were

reviewed. Innovations needed for these criteria, design solutions, and certification procedures were highlighted and comments provided on lessons learned.

Farmer's lecture reflected his lifelong professional commitment to reliability analysis. In addition to being a solid technical presentation, it provided excellent historical perspectives and was laced with interesting facts, statistics, and anecdotal material. Professor Farmer's keynote lecture was entitled, "The Appreciation and Control of Risks of Major Hazards as Developed by the Nuclear Industry," and after giving examples of the trends for risk reduction in major human activities over the past 100 years, he presented a framework to compare and assess the severity of new risks as compared to a simplified but quantified view of individual risk of death. Meaningful risk assessment, of course, is one of the foundations of modern reliability approaches.

Professor Kobori presented a thorough review of the reliability analysis for an important earthquake-resistant structure. In his presentation, several basic problems associated with safety estimates of critical structures such as nuclear reactor structures were discussed. Both engineering seismology and earthquake resistant design were treated. Regarding seismic analysis, uncertainty of the earth structure or foundation conditions, as well as quake source uncertainties, were included. The seismic response was extended to encompass nonlinear soil structure interaction. Reliability estimates were based on the probability density function of absolute maximum response and first passage failure. The presentation concluded with a discussion of the total system interaction, that is, the main structure, the foundation system, the boundary layer and soil medium as affected by the earthquake ground motion model. In retrospect, having experienced three moderate earthquakes in Tokyo, I must say I would now pay more attention to his lectures!

Perhaps the simplest way to provide a brief review of the conference is to summarize the meeting subject matter and then comment on a few selected topics especially related to the reliability mechanics of advanced materials. Let me begin with a summary of the topics covered at the various sessions.

SUMMARY OF TOPICS

Topic	Number Of Sessions
Technical Papers	
Reliability Theory	3
Systems Reliability	2
Reliability-based Design	2
Optimal Design	2
Gross Errors and Human Factors	1
Inspection	1
Random Vibration	3
Loads and Combinations	1
Fatigue Reliability	5
Probabilistic Fracture Mechanics	4
Probabilistic Finite Elements	1
Earthquakes	4
Wind Engineering	1
Soil Mechanics	3
Nuclear Structures	2

Bridges	2
Marine Structures	2

Current Research Sessions

Reliability Analysis	3
Probabilistic Analysis	2
Random Vibration	1
Reliability in Fatigue and Fracture	2
Earthquakes	2
Bridges	1
Marine Structures	2
Grand Totals	52 Sessions---- 213 Papers

- Reliability Mechanics of Advanced Materials

Several sessions dealt with high performance structural ceramics and with reinforced composites in general, but I will concentrate my discussions on the former. Therefore, I will discuss the session entitled, "Stochastic Fracture Mechanics" (T24C). The three papers presented in this session treated probabilistic fracture mechanics especially related to brittle ceramics.

Yamada and Hoshide addressed the problem of estimating fracture behavior under static loadings as compared to cyclic loadings. The authors cited literature presenting divergent results, e.g., the existence or not of stress cycling effects on fracture strengths. Therefore, they launched their own investigation of such effects. Experiments were conducted on a sintered silicon nitride produced by the NKK Spark Plug Company, Ltd.; Fracture tests under constant as well as cyclic loadings were completed on three-point beams and on ring compression specimens. Precracked specimens were used to investigate the influence of flaw size on strength and to study crack growth characteristics. Surface flaws were induced by means of Vickers indentor and specimens were annealed for two hours in vacuum at 800°C.

Regarding the relationships between strengths and natural flaws, the authors apply the usual simplifying assumptions, using two parameter Weibull models for strengths, simple power law for crack growth, and the deterministic approximations which have proliferated over the past dozen years. In presenting their correlations of fracture strength and equivalent crack lengths, they demonstrate as has been done by numerous other researchers, that inherent flaws do not follow the simple linear elastic and simplified fracture mechanics formulations which have become so prevalent. Their experimental observations, conducted at room temperature, illustrate departures from linearity, particularly for equivalent crack sizes under 50 M. Yamada and Hoshide reiterated what has been stated by earlier researchers, namely that when flaws become of the same order of magnitude as the microstructure, then continuum mechanics-based fracture mechanics approaches can not reasonably be expected to apply. Regarding the prediction of fatigue life based on static loading materials parameter characterization, they report good coincidence between predicted and observed fatigue behavior. Of course their experimental results exhibit fairly large scatter, and it is worth noting that the authors did not provide confidence limits on their calculations. Unfortunately, the lack of confidence limits for such calculations is commonplace but crucial to true verification.

The second paper in this session, authored by S. Aoki, I. Ohta, M. Sakata, and H. Ohnabe was a more sophisticated exploration of probabilistic fracture mechanics. The authors attempt to develop a unified theory for predicting probability of fracture and the distribution of fracture location in delayed failure. Their calculations combined stochastic process theory and the extreme value distributions for crack lengths. They also present an application of their methodology to finite element analysis of the root of a rotating ceramic gas turbine blade. In order to attempt to verify their analytical model, the authors carried out experiments on soda-lime glass using three- and four-point bend tests, in fast as well as delayed fracture tests. Experiments were conducted in water at room temperature. Weibull parameters were estimated by best-fit lines on logarithmic scales rather than more appropriate maximum likelihood estimating techniques. While the authors present graphical, or visual demonstration to support good agreement of experimental and analytical results, no confidence limits are given for their calculations. Nonetheless, their estimates of fracture location, compared to observed distributions, are impressive. It would be interesting to explore applicability to high temperature response of advanced ceramics, where multimode failure phenomena are active.

The authors also attempt to deal with the multiaxial stress state, and present two equations which they consider to be upper and lower bounds on probability of failure. Using a rather coarse mesh, they show that the differences of probability of failure for these two equations are rather small for an idealized turbine blade analysis. However, they also demonstrate the calculations for failure times require finer mesh sizes and no doubt the upper and lower bound estimates would be sensitive to improved gridding in a more refined finite element analysis.

The last paper in this session was coauthored by Yohtaro Matsuo, Eiichi Yasuda, and Shiushichi Kimura. They also investigated estimating time dependent strength distribution both analytically and experimentally. Three- and four-point bending tests were conducted in air and in vacuum, at various stressing rates, and for different size specimens. The material studied was steatite ceramic and the experiments were at room temperature. Regarding time dependent failure of brittle materials; in the past decade it has become fashionable to combine a deterministic slow crack-growth "law," usually a power law, with extreme value statistics. The authors follow this well-trodden path. Their formulation uses a Weibull bimodal function to represent the inert strength distribution, representing surface as well as internal flaws. Based on experimental results, model parameters are estimated using maximum logarithmic likelihood estimators. The authors contend they have obtained good agreement with experimental data, once again using the graphical appeal of estimating curves which visually appear to pass through the data point.

These previous papers indicate state-of-the-art capability to produce probability of failure estimates under relatively benign environments. Since the audience consisted mainly of applied mathematicians and reliability specialists, detailed aspects of materials science and realistic modeling of phenomenological response did not receive attention. These same comments also hold true for the few papers that were presented on composite materials (reinforced plastics). All told, 11 sessions dealt with materials-related issues pertinent to fracture and fatigue behavior and associated materials performance predictions. Of course, the dominant materials were metals and concrete. For these materials, the reliability treatments were quite advanced, somewhat in contrast to the more advanced materials. Perhaps this is due to the relatively small advanced materials specialists community and the much smaller experience base for the more recent materials. From this perspective, this meeting may be viewed as an introductory event which hopefully will stimulate productive interaction between materials science

specialists, applied mathematicians, and specialists in stochastic theory. In general, it is safe to state that considerable research remains to be accomplished in application of advanced probabilistic theories to the prediction of response for structural ceramics and composites. On the one hand, the materials scientists who are cognizant of fundamental phenomenological characteristics are not well trained in stochastic theories or applied mechanics. Therefore, they tend to resort to levels of simplification and approximation which permit them to conduct so-called life prediction and strength estimates. Much of the work to date thus involves combinations of deterministic and stochastic approaches, along with neglect of major failure modes. Progress is impeded by the complexity of the analytical treatments which are truly representative, and the enormous experiment effort and associated costs to adequately verify the more accurate methodologies.

CONCLUSION

I refer to the opening event of this ICOSSAR '85, the Freudenthal Memorial Session. Professors Konishi, Shinozuka, and Schueller paid touching tribute to the man and his work and set the tone for the meeting, which was of the highest professional caliber. The content conduct and accomplishments of the conference were indeed another important and fitting tribute to the memory of this pioneer in structural safety and reliability.

INTERNATIONAL MEETINGS IN THE FAR EAST

1986-1989

Compiled by Yuko Ushino

The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1986

Date	Title, Attendance	Site	For information, contact
January 21-22	IAE International Symposium on Fuel Cells, Advanced Fuel Cells, and Advanced Batteries	Tokyo, Japan	Mr. H. Hasuike, The Institute of Applied Energy 1-1-13 Shinbashi, Minato-ku, Tokyo 105
January 28-31	The 4th Australian Conference on Atomic and Molecular Physics and Quantum Chemistry	Hobart, Australia	Professor F. P. Larkins, Chemistry Department, University of Tasmania GPO Box 252C, Hobart, Tas 7000
February 1-9	International Volcanological Congress	Auckland, New Zealand	Professor H.-U. Schmincke, Institut für Mineralogie, Ruhr-Universität Bochum Universitätsstr 150, Postfach 10 21 48, D-463 Bochum, Federal Republic of Germany
February 2-8	Excited and Ionised States of Atoms and Molecules Workshop	Hobart, Australia	Professor F. P. Larkins, Chemistry Department, University of Tasmania GPO Box 252C, Hobart, Tas 7000
February 3-9	The 5th World Congress of the International Rehabilitation Medicine Association	Manila, Republic of Philippines	Dr. Tyrone Reyes, Chairman, IRMA-V, Philippine Congress Organization Center P.O. Box 4486 Metro Manila
February 12-14	Australian Neuroscience Society-Annual Conference	Perth, Australia	Dr. Lyn Beazley, Department of Psychology, University of Western Australia Nedlands, WA 6009
February 15-21	The 9th Australian Electron Microscopy Conference	Sydney, Australia	Conference Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601

Date	Title, Attendance	Site	For information, contact
February 16-23	The 8th Australian Geological Convention	Adelaide, Australia	Dr. C. Branch, Convenor, The 8th Australian Geological Convention Box 292, Eastwood, SA 5063
March (tentative)	The 2nd Asian Pacific Congress on Legal Medicine and Forensic Sciences	Adelaide, Australia	Dr. Andrew Scott, Forensic Science Center, Divett Place, Adelaide S.A. 5000
March (tentative)	The 6th Conference of the De Bakey International Surgical Society	Melbourne, Australia	D. G. Macleish 96 Grattan Street, Carlton, Victoria 3053
April 8-11	1986 International Conference on Acoustic, Speech, and Signal Processing (ICASSP '86)	Tokyo, Japan	Professor Hiroya Fujisaki, Department of Electronic, Faculty of Engineering, Tokyo University 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
April 13-17	The 5th International Symposium on Offshore Mechanics and Arctic Engineering	Tokyo, Japan	Jin S. Chung, Department of Engineering, Colorado School of Mines Golden, Colorado 80401, USA
April 14-18	Annual Engineering Conference	Adelaide, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
April 22-25	Computer Graphics Tokyo '86	Tokyo, Japan	The Secretariat of Computer Graphics Tokyo '86 c/o Japan Management Association 3-1-22 Shiba-Koen, Minato-ku, Tokyo 105
May 1-2	Australian Academy of Science--Annual General Meeting	Canberra, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2600
May 11-15	Royal Australian Chemical Institute, Division of Organic Chemistry--National Meeting	Adelaide, Australia	Dr. D. P. G. Hamon, C/-Organic Chemistry Division, Royal Australian Chemical Institute

Date	Title, Attendance	Site	For information, contact
May 11-16	The 13th Congress of the Council of Mining and Metallurgical Institutions	Canberra, Australia	The Australian Institute of Mining and Metallurgy PO Box 310, Carlton South, Victoria 3053
May 11-17	Congress of the International Society of Haematology and the International Society of Blood Transfusions	Sydney, Australia	Dr. I. Cooper, President, Haematology Society of Australia, Cancer Institute 481 Little Lonsdale Street, Melbourne, Victoria 3001
May 12-14	The 3rd Conference on Control Engineering--"Towards a more Competitive Industry"	Sydney, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
May 13-16	Annual Meeting of the Australian Biochemical Society	Melbourne, Australia	Professor G. Schreiber, Biochemistry Department, University of Melbourne Parkville, Victoria 3052
May 14-16	The 1st Australian Software Engineering Conference	Canberra, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
May 18-21	The 4th Conference on Semi-Insulating III-V Materials	Hakone, Japan	Secretariat: The 4th Conference on Semi-Insulating III-V Materials c/o International Congress Service, Inc. Kasho Building, 2-14-9 Nihonbashi, Chuo-ku, Tokyo 103
May 19-21	1986 Metals Congress	Adelaide, Australia	Australian Institute of Metals C/-Australian Mineral Foundation, Conyngham Street, Glenside, SA 5065
May 19-23	International Conference on Advanced Composite Materials and Structures	Taipei, Taiwan, Republic of China	Professor George C. Sih, Institute of Fracture and Solid Mechanics Packard Laboratory, Building No. 19 Lehigh University Bethlehem, Pennsylvania 18015, USA
May 25-29	International Conference on Computational Mechanics (ICCM86-TOKYO)	Tokyo, Japan	Secretariat of ICCM86-TOKYO c/o Professor G. Yagawa Department of Nuclear Engineering University of Tokyo 7-3-1 Hongo, Bunkyo-ku, Tokyo 113

1986

Date	Title, Attendance*	Site	For information, contact
May 28-30	International Congress Biliary Association (IBA) 20-F200-J300*	Sendai, Japan	Secretariat: International Congress of Biliary Association c/o International Congress Service, Inc. Kasho Building, 2-14-9 Nihombashi, Chuo-ku, Tokyo 103
May 28-30	The 4th Micro-Electronics Conference (IMC '86)	Kobe, Japan	Secretariat: The 4th Micro-Electronics Conference c/o Japan Convention Service, Inc. Nippon Press Center Building, 2-2-1 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100
May (Tentative)	Biomedical Engineering Conference	Australia (undecided)	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
June 1-5	International Conference on Science and Technology of Synthetic Metals (ICSM'86)	Kyoto, Japan	Professor Tokio Yamabe, Division of Molecular Engineering, Faculty of Engineering, Kyoto University Yoshida-honmachi, Sakyo-ku, Kyoto 606
June 1-6	The 3rd International Conference on Geoscience Information	Adelaide, Australia	Organizing Committe for the 3rd International Conference on Geoscience Information, Australian Mineral Foundation Private Bag 97, Glenside, SA 5065
June 2-6	International Conference on Role of Fracture Mechanics in Modern Technology	Fukuoka, Japan	Professor George C. Sih, Institute of Fracture and Solid Mechanics Packard Laboratory, Building No. 19 Lehigh University Bethlehem, Pennsylvania 18015, USA
June 8-12	The 6th International Conference on High Power Particle Beams	Kobe, Japan	Professor Kazuo Imasaki, Institute of Laser Engineering, Osaka University 2-6 Yamadaoka, Suita-shi, Osaka 565

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.
No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

Date	Title, Attendance	Site	For information, contact
June 23-25	Third Japan-United States Conference on Composite Materials	Tokyo, Japan	Professor J. R. Vinson, University of Delaware Newark, Delaware 19716, USA
July 12-19	International Institute of Welding--Annual Assembly 1986 38-F400-J600	Tokyo, Japan	Japanese Organizing Committee of International Institute of Welding--Annual Assembly 1986 c/o Japan Welding Society 1-11 Kanda-Sakuma-cho, Chiyoda-ku, Tokyo 101
July 15-18	International Conference on Electrical Contacts, Electromechanical Components and their Applications 15-F50-J130	Nagoya, Japan	Study Meeting of Electromechanical Components Association c/o Mano Research Development Technical Center, 606 Marine Heights, 5-1 Tashiro-Hondori Chikusa-ku, Nagoya 464
July 21-25	The 4th International Congress on Toxicology N.A.-F700-J800	Tokyo, Japan	Secretariat of 4th International Congress on Toxicology c/o International Congress Service, Inc. Kasho Building, 2-14-9 Nihombashi, Chuo-ku, Tokyo 103
August 3-7	The 20th Congress of the International Association of Logopedics and Phoniatrics 36-F300-J500	Tokyo, Japan	Japan Society of Logopedics and Phoniatrics c/o Research Institute of Logopedics and Phoniatrics, Faculty of Medicine, Tokyo University 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
August 11-15	The 4th International Kimberlite Conference	Perth, Australia	Dr. A. F. Trendall, Director, Geological Survey of WA 66 Adelaide Terrace, Perth, WA 6000
August 17-22	The 7th International Zeolite Conference 20-F200-J300	Tokyo, Japan	Dr. H. Tominaga, Department of Synthetic Chemistry, Faculty of Engineering, Tokyo University 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
August 18-21	The 2nd SPSJ (The Society of Polymer Science, Japan) International Polymer Conference	Tokyo, Japan	The Society of Polymer Science, Japan 5-12-8 Ginza, Chuo-ku, Tokyo 104
August 20-22	1986 International Conference on Solid State Devices and Materials 20-F200-J800	Tokyo, Japan	Organizing Committee of Conference on Solid State Devices and Materials c/o Business Center for Academic Societies, Japan 2-4-16 Yayoi, Bunkyo-ku, Tokyo 113

Date	Title, Attendance	Site	For information, contact
August 24-29	The 8th IUPAC Conference on Physical Organic Chemistry 18-F350-J600	Tokyo, Japan	Dr. Minoru Hirota, Secretary General, The 8th IUPAC Conference on Physical Organic Chemistry c/o Chemical Society of Japan 1-5 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
August 24-30	Internat:.mal Conference on Atomic Physics and Few Body Systems 40-F200-J800	Tokyo and Sendai, Japan	Dr. Tsutomu Watanabe, Institute of Physical and Chemical Research 2-1 Hirosawa, Wako, Saitama 351-01
August 24-30	The 6th International Congress of Parasitology	Brisbane, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
August 25-29	The 12th International Sedimentological Congress	Canberra, Australia	Australian Convention and Travel Services GPO Box 1929, Canberra, ACT 2601
August 25-29	The 7th International Union of Air Pollution Prevention Associations Congress	Sydney, Australia	R. W. Manuell, Seretary, Clean Air Society of Australia and New Zealand P.O. Box 191, Eastwood, NSW 2122
August 26-30	International Conference on Martensitic Transformations (ICOMAT-86)	Nara, Japan	Conference Secretariat, ICOMAT-86, Japan Institute of Metals Aoba, Aramaki, Sendai 980
August 27-30	The 33rd Annual General Meeting of Genetics Society of Australia	Adelaide, Australia	Dr. D. E. A. Catcheside, School of Biological Sciences, Flinders University of SA Bedford Park, SA 5042
August 28-30	Rotating Machines Conference	Melbourne, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 31-September 7	The 11th International Congress on Electron Microscopy 56-F1,000-J1,600	Kyoto, Japan	Professor K. Ogawa, Department of Anatomy, Faculty of Medicine, Kyoto University Yoshida Konoe-cho, Sakyo-ku, Kyoto 606
September 1-6	International Association for Bridge and Structural Engineering Symposium--(IABSE) 30-F250-J330	Tokyo, Japan	Secretariat of IABSE c/o International Congress Service, Inc. Kasho Building, 2-14-9 Nihombashi, Chuo-ku, Tokyo 103

1986

Date	Title, Attendance	Site	For information, contact
September 4-6	Safety and Quality Assurance of Civil Engineering Structures	Tokyo, Japan	Japanese Group of International Association for Bridge and Structural Engineering c/o Japan Society of Civil Engineers Yotsuya 1-chome, Shinjuku-ku, Tokyo 106
September 9-11	The 3rd International Conference on Science and Technology: Zirconia 37-F250-J350	Tokyo, Japan	Ceramics Society of Japan 2-22-17 Hyakunincho, Shinjuku-ku, Tokyo 160
September 21-25	World Congress of Chemical Engineering 35-F300-J1,000	Tokyo, Japan	Society of Chemical Engineers, Japan Kyoritsu Kaikan, 4-6-19 Honhinata, Bunkyo-ku, Tokyo 112
September 22-26	The 9th International Meeting of International Union of Phlebology 27-F200-J300	Kyoto, Japan	Dr. S. Sakakuchi, School of Medicine, Hamamatsu University 3600 Handa-cho, Hamamatsu, Shizuoka 431-31
September 25-October 1	The 7th International Congress of Eye Research 15-F600-J400	Nagoya, Japan	Professor Shuzo Iwata, Department of Biophysical Chemistry, Faculty of Pharmaceutical Science, Meijo University 15 Yagoto-Urayama, Tempaku-cho, Tempaku-ku, Nagoya 488
September 30-October 2	The 6th International Display Research Conference (Japan Display '86) 26-F200-J450	Tokyo, Japan	Secretariat: The 6th International Display '86 Research Conference c/o Japan Convention Services, Inc. Nippon Press Center Building, 2-1-2 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100
October 7-9	The 4th International Conference on Optical Fiber Sensors (OFS '86)	Tokyo, Japan	Secretariat: The 4th International Conference on Optical Fiber Sensors c/o Hikari Sangyo Gijutsu Shinko Kyokai, 20th Mori Building, 2-7-4 Nishi-Shinbashi, Minato-ku, Tokyo 105
October 20-25	The 11th International Conference on Cyclotrons and Their Applications 17-F150-J150	Tokyo, Japan	Dr. Yasuo Hirao, Institute for Nuclear Study, University of Tokyo 3-2-1 Midori-cho, Tanashi, Tokyo 188
November 4-7	CIE 1986 International Conference on Radar (CICR-86)	Shanghai, People's Republic of China	Mr. Zhou Wensheng, China Academy of Electronic Technology P.O. Box 134, Beijing

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Date	Title, Attendance	Site	For information, contact
February 22-27	The 6th Conference and Exhibition on Exploration Geophysics	Perth, Australia	Dr. F. Fritz C/-BP Minerals, 200 Adelaide Terrace, Perth, WA 6000
April 14-17	The 25th International Magnetics Conference (INTERMAG '87) F500-J1000	Tokyo, Japan	The Magnetics Society of Japan Kotohira Kaikan Building, 1-2-8 Toranomon, Minato-ku, Tokyo 105
April 20-24	The 11th Particles and Nuclei International Conference (PANIC '87)	Tokyo, Japan	Professor Koji Nakai, National Laboratory for High Energy Physics 1-1 Uehara, Oho-machi, Tsukuba-gun, Ibaraki 305
April 30-May 1	Australian Academy of Science--Annual General Meeting	Canbella, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
May 17-22	World Conference on Advanced Materials for Innovations in Energy, Transportation, and Communications	Tokyo, Japan	CHEMRAWN VI Coordinating Office, The Chemical Society of Japan 1-5 Kanga-Surugadai, Chiyoda-ku, Tokyo 101
May (Tentative)	Symposium for Quantitative Aspects of the Nitrogen Cycle	Brisbane, Australia	Dr. R. J. Myers, CSIRO Division of Tropical Crops and Pastures St Lucia, QULD 4067
June 2-5	The 4th Printed Circuit World CongressJapan N.A.-F200-J800	Tokyo,	Japan Printed Circuit Association (JPCA) Tashiro Building, 5-11-10 Toranomon, Minato-ku, Tokyo 105
Undecided	The International Conference on Computers In Chemical Research and Education (the ICCCRE)	Shanghai, People's Republic of China	Dr. Yongzheng Hui, Shanghai Institute of Organic Chemistry, Academia Sinica 345 Lingling Lu, Shanghai 200032
August 12-20	The 14th International Congress of Crystallographers	Perth, Australia	Dr. E. N. Maslen, Centre forCrystallography, University of Western Australia WA 6009
August 19-26	The 18th International Conference on Low Temperature Physics	Kyoto, Japan	Professor Shinji Ogawa, The Institute for Solid State Physics, Tokyo University 7-22-1 Roppongi, Minato-ku, Tokyo 106

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Date	Title, Attendance	Site	For information, contact
August (tentative)	The 10th International Congress of Pharmacology	Sydney, Australia	Professor J. Shaw, Secretary, Interium Organising Committee, Department of Pharmacology, University of Sydney NSW 2006
August (tentative)	International Congress for Pharmacology, Satellite on Cardio-Active Drugs	Hayman Island, Australia	Australian Convention and Travel Services GPO Box 1929, Canberra, ACT 2601
October 20-23	International Conference on Quality Control--1987 Tokyo 40-F350-J350	Tokyo, Japan	Union of Japanese Scientists and Engineers 5-10-11 Sendagaya, Shibuya-ku, Tokyo 151

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Date	Title, Attendance	Site	For information, contact
January 28-31	Royal Australian Chemical Institute, Division of Inorganic Chemistry, National Meeting (COMO 13)	Melbourne, Australia	Dr. P. Tregloan, Department of Inorganic Chemistry, University of Melbourne Parkville, Victoria 3052
February 22-26	Engineering Conference	Sydney, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
April 26- May 3	The 3rd World Biomaterials Conference 15-F500-J500	Kyoto, Japan	Japan Society for Biomaterials c/o Institute for Medical and Dental Engineering, Tokyo Medical and Dental University 2-3-10 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
June 5-10	The 6th International Conference on Surface and Colloid Science	Hakone, Japan	Division of Colloid and Surface Chemistry, The Chemical Society of Japan 1-5 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
July 1-12	The 16th International Congress of Photogrammetry and Remote Sensing 65-F1,000-J1,000	Kyoto, Japan	Japan Society of Photogrammetry 601 Daiichi Honan Building, 2-8-17 Minami-Ikebukuro, Toshima-ku, Tokyo 171

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Date	Title, Attendance	Site	For information, contact
July 17-23	International Congress of Endocrinology N.A.-F1,500-J2,000	Kyoto, Japan	Japan Endocrine Society c/o Seirenkaikan Kyoto Furitsu Medical University Nishizume Konjinbashi, Kamigyo-ku, Kyoto 602
August 1-5	The 10th Congress of the International Ergonomics Association	Sydney, Australia	Ergonomics Society of Australia and New Zealand, Science Centre 35-43 Clarence Street, Sydney, NSW 2000
August 1-6	IUPAC International Symposium on Macromolecules	Kyoto, Japan	The Society of Polymer Science, Japan 5-12-8 Ginza, Chuo-ku, Tokyo 104
August 15-19	The 3rd International Phycological Congress	Melbourne, Australia	Dr. M. N. Clayton, Botany Department, Monash University Clayton, Victoria 3168
August 21-26	International Geographical Congress	Sydney, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
September 5-9	The 16th World Congress of Rehabilitation International 90-F1,500-J1,000	Tokyo, Japan	Japanese Society for Rehabilitation of the Disabled, Inc. 3-13-15 Higashi-Ikebukuro, Toshima-ku, Tokyo 107
November 19-26	The 13th International Diabetes Federation Congress	Sydney, Australia	Professor J. R. Turtle, Professor of Medicine Department of Endocrinology, University of Sydney NSW 2006

1989

Date	Title, Attendance	Site	For information, contact
1989 (tentative)	International Conference on Coordination Chemistry	Brisbane, Australia	Professor M.A. Bennett, Research School of Chemistry, ANU P.O. Box 4, Canberra, ACT 2601

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